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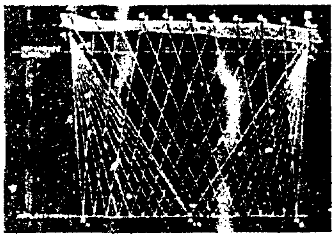

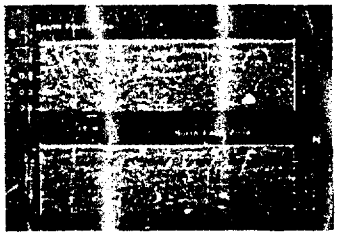

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REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-GT-10

HIGH-RESOLUTION SEISMIC REFLECTION INVESTIGATIONS AT BEAVER DAM, ARKANSAS

by

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	Problem Area		Problem Area
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP - Seismic Reflection Survey, Beaver Dam, Arkansas.
MIDDLE - Concept of Seismic Reflection.
BOTTOM - Seismic Reflection Record, Beaver Dam, Arkansas.

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Seismic refraction surveys require line lengths four to five times the desired depth of investigation. For many geotechnical applications, these are physical and geometrical constraints which inhibit seismic refraction, such as narrow river valleys, changes in direction of the center line of a dam, or legal inaccessibility to land surrounding a site. The seismic reflection method offers an alternative to refraction for geotechnical site investigations. Typical line lengths for reflection are approximately equal to the desired depth of investigation. In the past, the required data processing, limitations of "engineering seismographs," and inapplicability of oil exploration seismic recording systems to very shallow targets (< 30 m) precluded effective utilization of the seismic reflection method for geotechnical applications. Rapid advances in microcomputer technology, development of digital engineering seismographs, development of high frequency seismic sources,

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and adaptation of oil exploration field procedures to account for inherent problems of shallow depths of investigation now make shallow, high-resolution seismic reflection surveys a viable tool for geotechnical applications.

Field investigations of shallow, high-resolution seismic reflection methodology at an existing structure site, Dike 1, Beaver Dam, AR are discussed. Dike 1 is built across a graben with vertical offset in excess of 70 m. The down dropped block consists of solutioned, cherty limestone. The top of rock is highly irregular, and solution cavities and solution-widened joints exist in the rock. The seismic reflection results effectively mapped the irregular top of rock (3 to 10 m depth), detected previously unknown faults within the graben, and mapped sandstone and shale formations at the "base" of the graben (70 to 75 m depth).

PREFACE

This work was performed from July 1985 to January 1986 by personnel of the Department of Geophysics, Colorado School of Mines (CSM), Golden, CO, and Instrumentation Services Division (ISD), US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The work was supported under an Intergovernmental Personnel Act Agreement between CSM and WES. This work was jointly funded by the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program, Work Unit 32315, "Geophysical Techniques for Assessment of Existing Structures and Structural Foundations," and the Little Rock District, Corps of Engineers under Intra-Army Order No. 85-0045. The fieldwork was performed during August 1985 and benefited greatly from the use of rental equipment and field personnel labor covered by Contract DACA 39-86-K-0008, "Active Geophysical Methods Applied to the Tunnel Detection Problem." The Technical Monitor was Mr. Ben Kelly.

CSM Principal Investigator for the work was Dr. Thomas L. Dobecki. Mr. Monroe B. Savage, ISD, WES, and Messrs. Thomas Kertesz, Jeff Meis, and Scott Stephens, CSM, were responsible for field data acquisition. Data processing and interpretation were performed with the additional assistance of Ms. Tanya L. Mueller, CSM. Technical monitoring was performed by Dr. Dwain K. Butler and Mr. Jose L. Llopis, Geotechnical Laboratory (GL), Earthquake Engineering and Geophysics Divison (EEGD), who were also Principal Investigators of the REMR Work Unit. Mr. Jerry Huie, Engineering Geology and Rock Mechanics Division, was the Geotechnical (Rock) Problem Area Leader, and Mr. William F. McCleese is REMR Program Manager. Dr. Arley G. Franklin is Chief, EEGD, and Dr. William F. Marcuson III is Chief, GL. The report was edited by Ms. Odell F. Allen, Information Management Division, Information Technology Laboratory.

Acting Commander and Director of WES during the preparation of this report was LTC Jack R. Stephens, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

HIGH-RESOLUTION SEISMIC REFLECTION INVESTIGATIONS AT BEAVER DAM, ARKANSAS

PART I: INTRODUCTION

1. Shallow seismic stratigraphic surveying has been ignored typically by the engineering industry as a tool for finding shallow anomalies and delineating weathered zones that may adversely affect foundation conditions. The Beaver Dam project attempts to show that the use of high-resolution seismic data can be important to studies of fractures, cavities/voids, irregular (weathered) top of rock, and other near-surface anomalies. Three seismic reflection lines were shot downstream from the face of Dike No. 1, Beaver Dam, AR, which is known to be leaking impounded water through subsurface foundation formations. Although other geophysical methods have been used at the damsite in hope of finding where and why leakage (anomalous seepage) occurs, it was hoped that high-resolution seismic reflection surveys could give an even more accurate idea of where faulted zones are located and their relationship to observed leakage. Further, with the Corps of Engineers program for certification and rehabilitation of existing dams, it was felt that Beaver Dam would provide an excellent test case to evaluate the utility of seismic reflection for evaluating anomalies related to seepage.

2. The Beaver Dam seismic reflection project was undertaken by the Colorado School of Mines (CSM), Geophysics Department, with several goals in mind. Because of the known foundation structural problems mentioned, the earthen Dike No. 1 has been under scrutiny for anomalous seepage since it was built. It was hoped that high-resolution seismic data could resolve both basement structures (more precisely define fault zones) and in addition, resolve suspected large vugs*, voids, or zones of intense weathering.

3. Dike No. 1 is situated just north of the main concrete dam and embankment and occupies a low bedrock area which would otherwise be below pool level. Geologically, the dike straddles a graben of estimated 305-m width and 76-m throw. This downdropped section has brought a vuggy carbonate formation

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* Specialized and perhaps unfamiliar geophysical terms that are underlined are defined in Appendix A.

(see Part II) down to a lowered elevation such that it is the foundation rock for the dike. It is well above the top of the main embankment. This circumstance and the fracturing attending the graben boundary faults are suspected to be the causes of seepage detected along the face of and downstream from Dike No. 1.

4. The US Army Engineer Waterways Experiment Station (WES), as part of its REMR research program, is investigating the use of seismic reflection for the evaluation of existing dams and adjacent structures. At Beaver Dam, WES has already employed seismic refraction, electrical resistivity, magnetic, electromagnetic, ground penetrating radar, and self-potential (SP) surveys along the dike. These surveys (US Army Corps of Engineers 1986; Llopis and Butler 1988) have pointed out anomalous conditions at the soil-rock interface (refraction) and localized fluid flow patterns (SP). WES felt, however, that Beaver Dam would be an ideal site for testing the utility of seismic reflection, given the parallel refraction and extensive SP data, ground penetrating radar, and borehole investigations already performed at this location. Given the shallow penetration of radar and refraction (because of thick, relatively uniform velocity stratigraphy and the physical limitations on refraction survey line length) and the sensitivity of SP to flow and not structure, seismic reflection surveys can provide the following information:

- a. Lateral location and description of boundary and any other faults which affect the upper (approximately) 0 to 300 m.
- b. Detection of localized cavities/voids associated with the vuggy Boone formation and/or faulted zones.
- c. Correlation of the above with patterns of seepage determined by other means.

5. An additional purpose in the seismic reflection investigation was to evaluate different instrumentation and data acquisition methodologies to determine optimal means for acquiring such data while retaining high data quality.

PART II: GEOLOGIC SETTING

6. Beaver Dam is located on the White River, Ozark Uplift in Northern Arkansas (Figure 1). The dam and other structures are founded on flat-lying Paleozoic carbonate sedimentary rocks. The region is quite hilly as the White River and its tributaries have steeply dissected these carbonates. Five of these Paleozoic formations outcrop in the vicinity of the dam; these are named and described in Figure 2. It is important to note that the Boone formation, a cherty limestone, is the host rock for most of the springs and natural caverns found throughout this region (US Army Corps of Engineers 1986).

7. The presence of this formation in the region of the dam might have caused grave concern initially had it not been for the fact that the Boone formation is situated at an elevation above the dam and reservoir on the south abutment. The misfortune is that these flat-lying sedimentary rocks have been offset by normal faulting such that Dike No. 1 occupies a graben where the rocks have been downdropped in excess of 250 ft (76 m). As such, the foundation rock for Dike No. 1 is indeed the Boone formation. Much of the leakage observed is therefore felt attributable to the deteriorated character of this soluble foundation rock and its deformation and fracturing resulting from the close proximity to faulting.

8. In terms of candidate reflecting horizons in the Dike No. 1 area, likely candidates, listed by increasing subsurface depth are:

a. Fill/weathered rock interface.

b. Weathered/solid rock interface.

c. Boone/Chatanooga/Sylamore contacts at >200 ft (61 m).

d. Dense or weak zones within the Cotter fm (Figure 2).

e. Crystalline basement (suspected depth >1,500 ft (457 m).

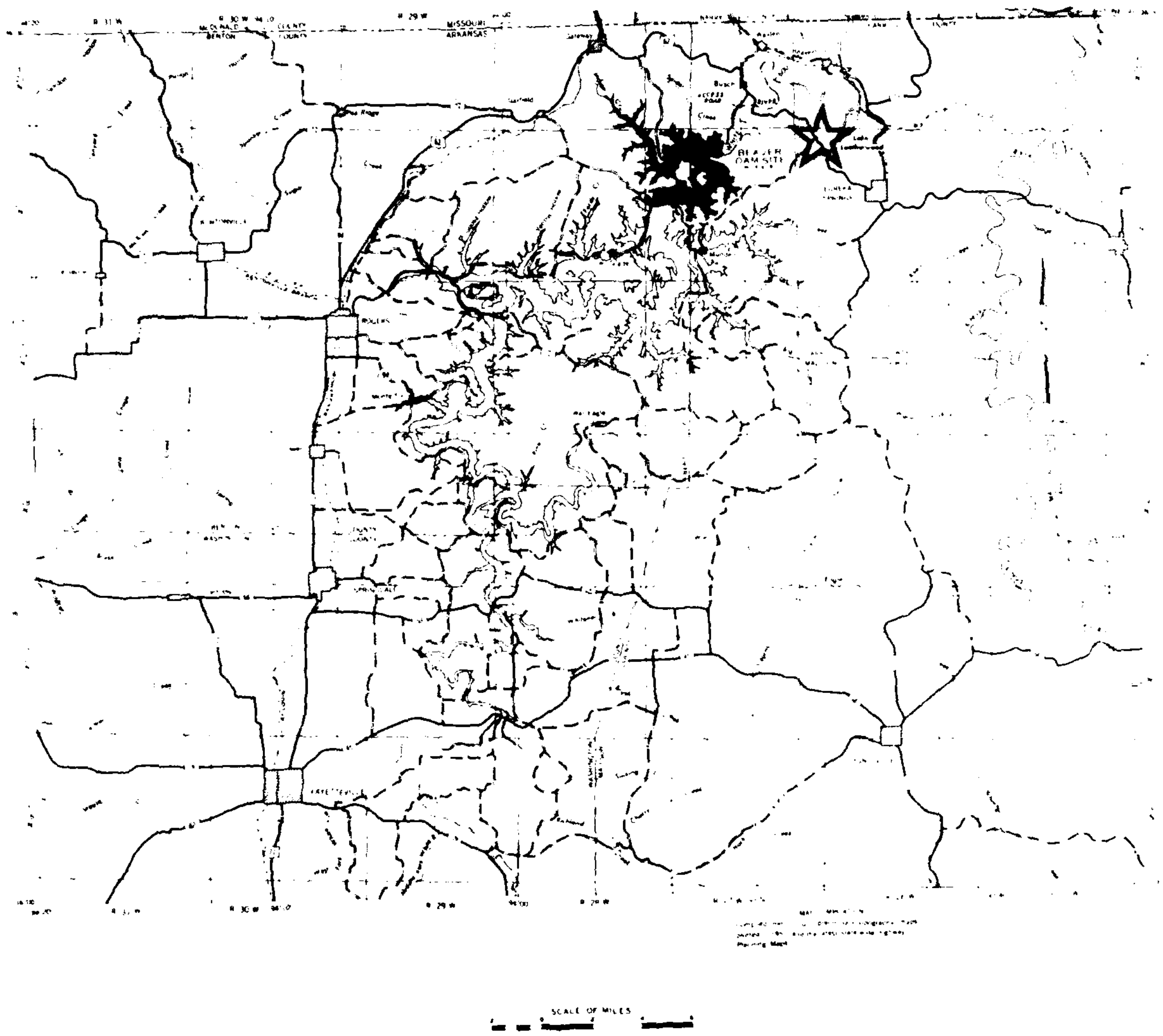


Figure 1. Site location map, Beaver Dam, Arkansas

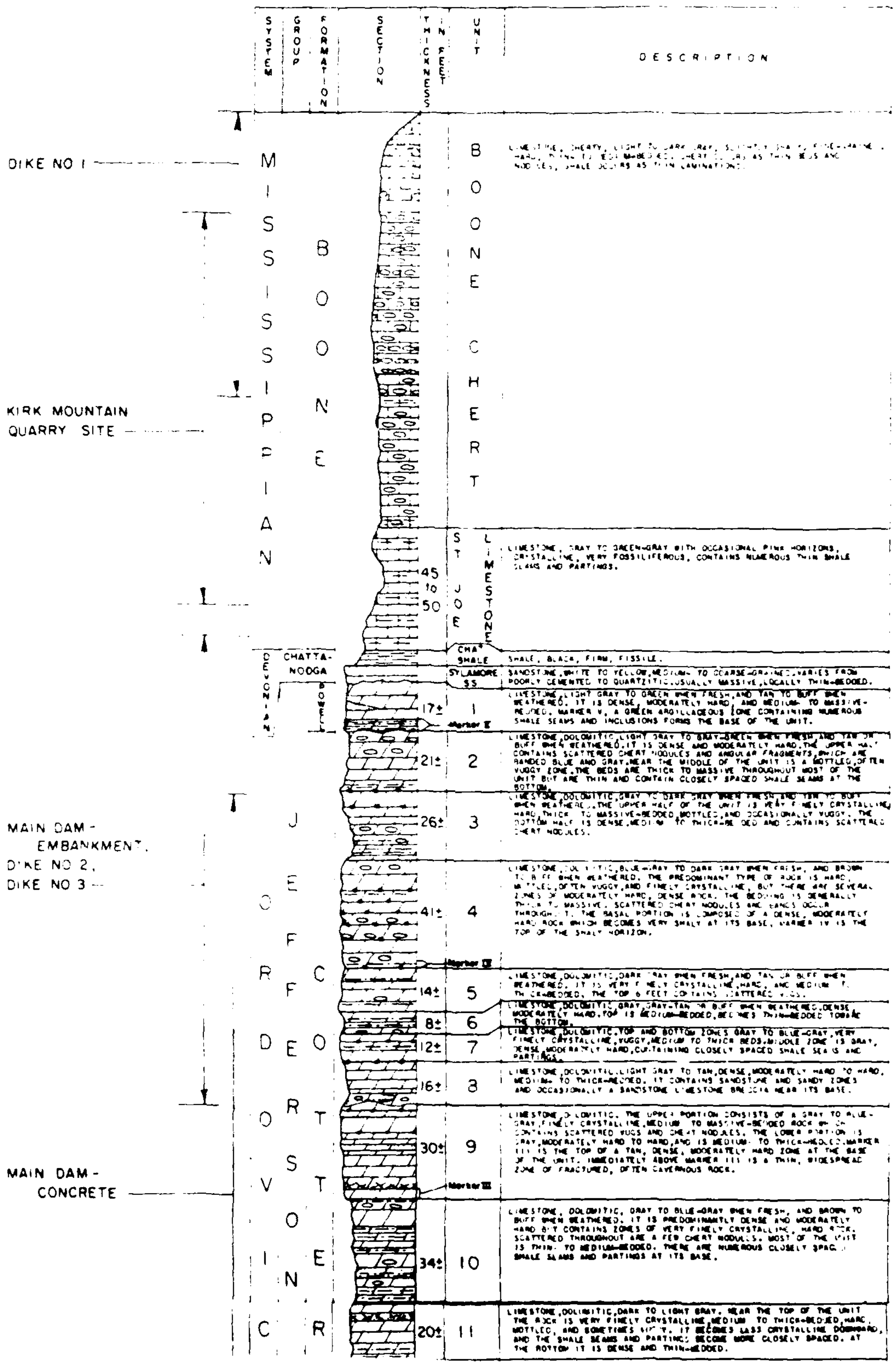


Figure 2. Stratigraphic column at Beaver Dam site

PART III: SEISMIC REFLECTION COMPARED WITH STANDARD SURVEYS

9. Traditional geophysical surveys in support of geotechnical site characterization have been dominated by (a) seismic refraction (b) cross-hole seismic testing, and (c) electrical resistivity (Dobecki and Romig 1985). Refraction in P- and S-wave modes provides fairly rapid areal coverage of a site yielding the depths (thicknesses) and configuration of subsurface layers as well as the compressional and/or the shear-wave velocity of each layer. This is true provided that the velocity of each successively deeper layer exceeds that of the layer above it. Even if this is satisfied, error can arise if a given layer is thin ("thin" may be as thick as several tens of meters); in such a circumstance, the thin layer escapes detection by refraction methods. Therefore, either low-velocity zones or thin, high-velocity layers may be missed by refraction even if the data were obtained perfectly (noise free). From an operational standpoint, refraction becomes difficult if the targeted refraction horizon (e.g. bedrock) is deep. The required shotpoint-to-geophone separation ("offset") to map the target effectively will be roughly three to five times the depth of the target. This requires long lines, which increases the chances for error due to lateral velocity variation. This also requires higher energy seismic sources such as dynamite to accommodate for added attenuation of signal strength over the long travel path. Oftentimes, logistical, topographic, or political influences can limit the surface area available for data acquisition as well as the nature and strength of seismic sources which could be used. Finally, in areas of complex subsurface geology, refraction interpretation becomes extremely complicated (Palmer 1980).

10. Cross-hole seismic testing eliminates some of the problems associated with refraction by providing very fine sampling of the subsurface P- and S-wave velocity distribution with depth by making these as time-of-flight measurements between boreholes. This is obtained however at the expense of the areal coverage obtained from refraction and with the expense of drilling two or more drillholes. As with refraction, some error may be associated with thin beds, particularly low velocity thin beds, but this error may be corrected if the presence of such thin beds is suspected (Butler and Curro 1981). Still, even given perfect data, no information is available from depths greater than that of the boreholes themselves.

11. Electrical resistivity in most geotechnical applications finds its greatest use in determining depths and/or shapes of saturated zones (such as water table or water-filled fracture zones) or in locating other conductive horizons (clay seams and highly weathered rock). Unlike the seismic methods, resistivity is not based upon elasticity theory. The only relationships which relate resistivity directly to rock strength parameters are empirical and highly site specific (Keller 1974). Further, since resistivity is a potential field technique (as opposed to a wave propagation technique), its resolution is theoretically much less than seismic methods.

12. Under many circumstances, the combination of these three techniques, tied to an exploratory borehole program, is totally adequate to support a geotechnical site investigation. The obvious situations where these would be inadequate include:

a. Sites where required depth of investigation exceeds (approximately) 50 to 100 m.

b. Sites characterized by the occurrence of low velocity layers such as clay layers or subhorizontal fracture zones at depth.

c. Sites with thin or small target zones in the subsurface which might otherwise require an extensive boring program.

d. Sites of limited access or of other logistical restriction (e.g. no explosives, presence of surface steel structures, etc.).

For such sites, the use of seismic reflection may be appropriate.

13. Seismic reflection uses shotpoint-to-geophone offsets comparable to the depth of the target as opposed to three to five times the depth for seismic refraction. This allows for shorter geophone spread lengths and smaller source energies for a given depth of investigation as compared with refraction. It is effective at detecting both high- and low-velocity beds at depth, although determination of the bed's velocity is not done very accurately. Reflection can also detect "thin" beds if the thickness of the bed is somewhat greater than 1/8 the dominant seismic wavelength. Increased resolution implies an increased bandwidth in the seismic wave/signal. Many of the shortcomings of refraction, cross-hole, and resistivity can therefore be eliminated or reduced with the addition of reflection to the geophysical investigation program.

14. Seismic reflection however has inherent problems of its own. Principally, obtaining good unambiguous reflection data free from interfering

"noise" (e.g., ground roll, airwave, refractions) can be very difficult. Obtaining good refraction data is generally quite easy; it may not be interpretable, but it is easy to acquire. Great care in instrumentation, field geometries, procedures, and subsequent data processing, however, are required just to produce a visible and coherent reflection on a record section. This requires greater skill on the part of the geophysicist. Once the reflection has been recorded with fidelity, interpretation itself is much less cumbersome than with refraction or resistivity.

PART IV: DATA ACQUISITION

Instrumentation

15. Seismic data were acquired using a 24-channel digital data acquisition system. The key specifications of this instrument are given below.

Acquisition Control Unit (ACU)

Sample interval	menu selected from 1/4, 1/2, 1, 2, or 4 msec
Low cut filters	menu selected from 5 to 320 Hz in 5 Hz increments; 18 db/octave
Alias filters	menu selectable; down 80 db at 128, 256, 512, 1,024, 2,048, and 4,096 Hz
Notch filters	menu selectable; 50 to 60 Hz (60 db down)
Acquisition mode	write digital data direct to tape or into mass storage memory, then to tape
Run time	limited only by available memory, typically 4.096 sec at 1/4 msec; 8.192 sec at 1/2 msec; etc.
Channels	24
Word size	15 bits plus 4-bits exponent representing 6 db gain steps
Amplifiers	Instantaneous floating point
Stacking	No limit to summing of successive signals
Display	CRT with menu selected fixed gain, fixed gain normalized, or digital AGC playback

Plotter

8.5 in. wide electrostatic paper; print contents of full CRT memory

Digital Tape Recorder

Spec's	7.5 in. reel, 1,200 ft tape, 1,600 bpi
Format	SEG D; menu selected multiplex or demultiplex

Post Acquisition Processor (PAP) Programs Available

Bandpass digital filtering of raw or processed data

Common offset gather

NMO correction

Transient suppression

Trace edit

Mute

FFT

Constant velocity CDP stack

16. Of utmost importance were the features of 15-bit recording (high dynamic range) instantaneous floating point amplifiers (rapid, accurate data acquisition) and post acquisition processing capability (in-field data analysis). WES itself has 12- and 24-channel "engineering" seismographs which it may wish to use for similar purposes on future projects. These seismographs do not have many of the special features of the CSM system. However, our procedures and analysis always kept the WES systems in mind to determine how appropriate these might be in their current format and/or how they might best be modified to allow for this usage.

Line C-1

17. Line C-1 runs, for the most part, coincident with SP Line C (Llopis and Butler 1988). It is roughly North-South, extending from north of the northern fault zone, across the downstream berm of Dike No. 1, across the southern fault zone, and part way down the main embankment (Figure 3). The line was flagged at 5-ft (1.5 m) intervals with Flag C-1 at the North and Flag C-359 at the South for a total line length of 1,790 ft (546 m).

18. Line C-1 was shot in common depth point (CDP) roll-along fashion as follows:

a. An optimum offset (distance from shotpoint to first of 24 geophones) of 125 ft (38 m) was determined by test shooting at several offsets.

b. Twenty-four geophone stations spaced at 5-ft (1.5 m) intervals were used (Figure 4). Each station is an array of six single geophones.

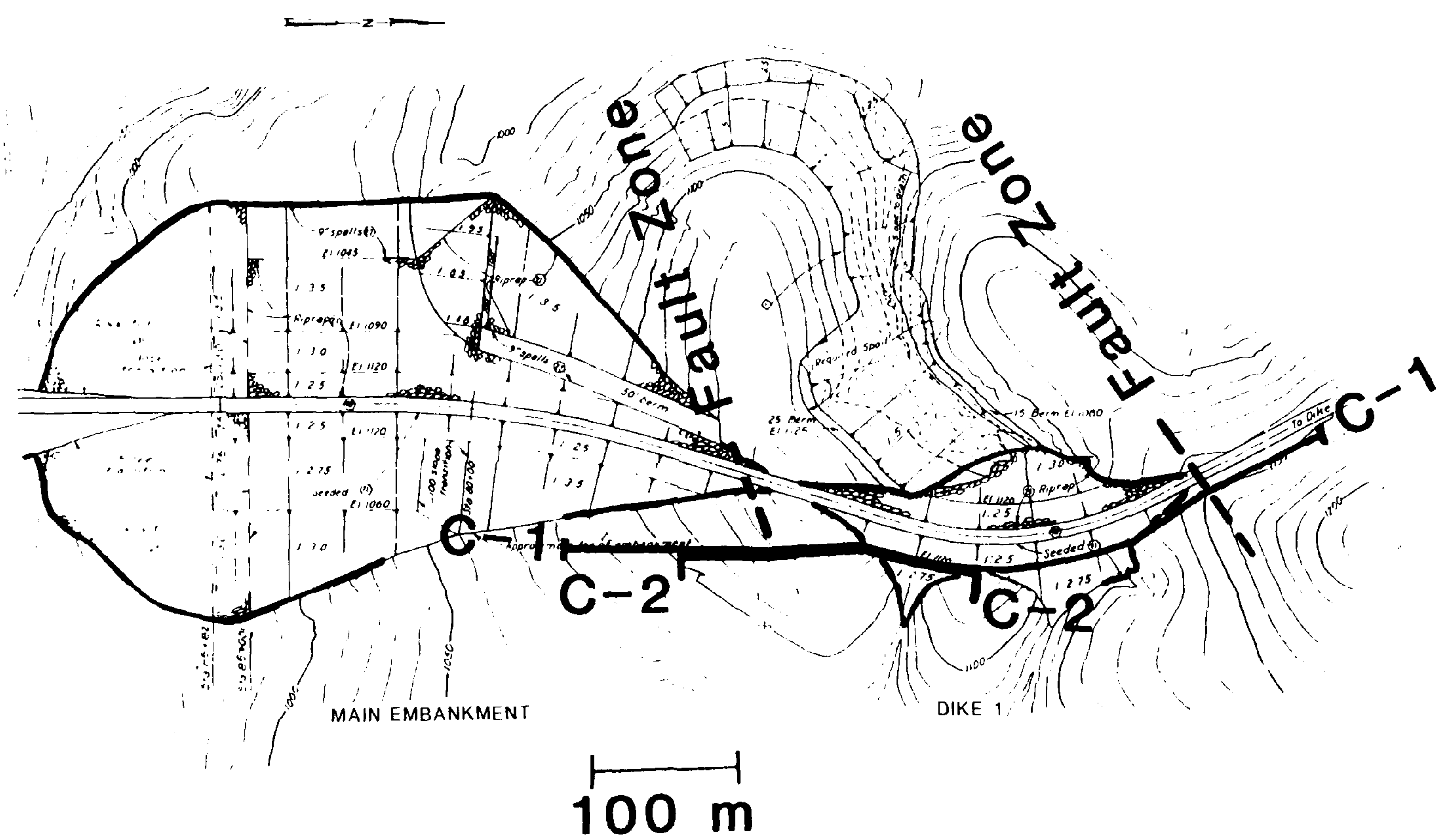


Figure 3. General layout of seismic lines, Beaver Dam

c. Each geophone station consisted of an array of six, series connected, 24 Hz geophones at 5-ft (1.5-m) element spacing.

d. The seismic source employed was three stacks of a shotgun shell ("Buffalo Gun") in a 2-ft (0.6-m) augered hole.

e. After recording, the entire arrangement was "rolled up" (advanced) two flag positions (10 ft or 3 m) and repeated.

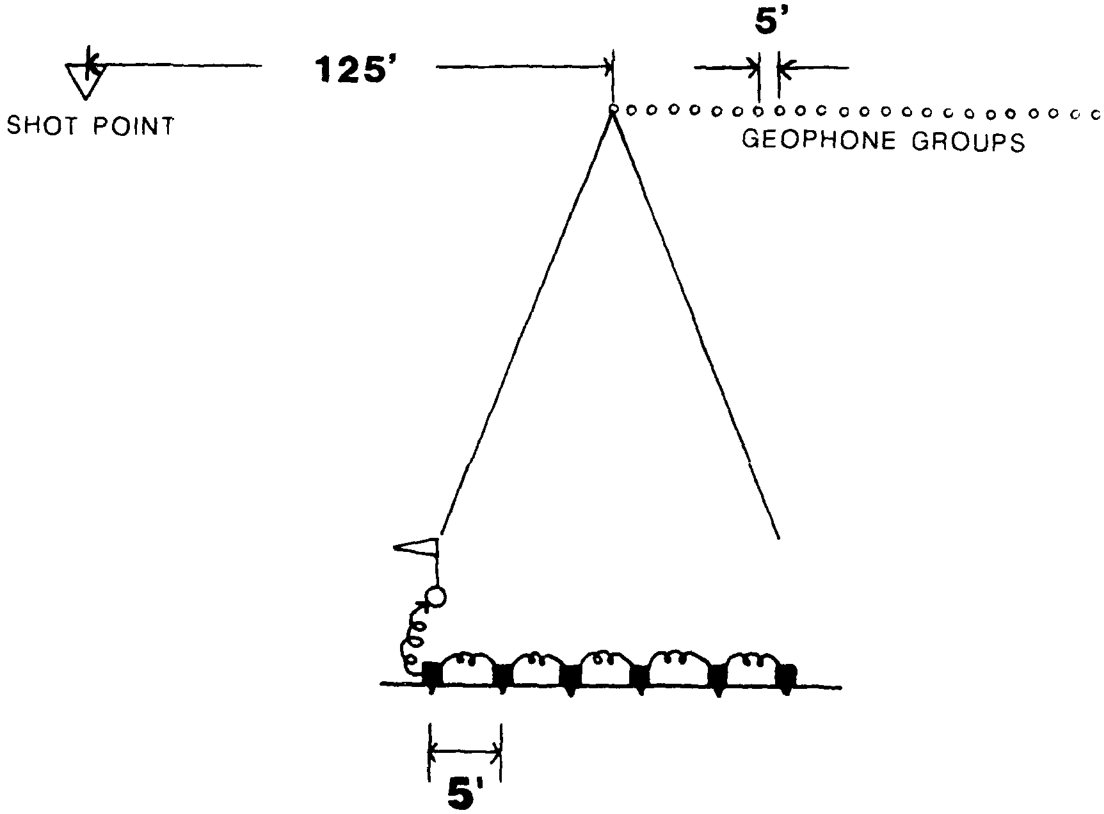


Figure 4. Shot, geophone layout for one shot record, Line C-1

19. The choices of offsets, geophone groups versus single phones, and Buffalo Gun source versus sledgehammer were based upon preliminary test spreads in the center of the graben area. The target reflector for this line was the Chatanooga/Sylamore beds at an estimated 250 ft (76 m) depth.

20. The resulting CDP coverage, given 24 geophone positions per shot and advancing the shot two stations between shots, is a maximum of 6-fold stack. Subsurface reflection point spacing is one-half that of the geophone spacing or 2.5 ft (0.8 m).

Line C-2

21. Line C-2 overlapped part of Line C-1 by using geophone stations at Flags C-171 through C-290 for a total line length of 595 ft (181 m). The differences in Lines C-1 and C-2 are how the data were acquired and what the target reflector was. The target reflector was the top of sound foundation rock estimated at 15 to 70 ft (4.6 to 21 m) from boring and WES refraction data along Dike No. 1.

22. With a shallow target, the shot-geophone offset was changed, and a switch was made from geophone groups to single geophones. The offset should, by the rule of thumb, be on the order of the target depth. The use of single phones for shallow reflections is because arrays tend to smear the high frequency components of the reflected signal if the reflection path is not near vertical. For a shallow reflection, this path is surely nonvertical. Therefore, Line C-2 was shot in CDP roll along fashion as follows:

- a. An optimum offset of 15 ft (4.6 m) was used.
- b. Twelve geophone stations spaced at 5-ft (1.5 m) intervals were used (Figure 5).
- c. Single, 100 Hz vertical geophones were used.
- d. The seismic source employed was four stacks of a sledgehammer on a steel plate.
- e. After recording, the entire arrangement was rolled up one flag position (5 ft or 1.5 m) and repeated.

In addition, ground roll reduction was obtained by employing a 320 Hz low cut filter (analog) prior to digitization. The resulting CDP coverage also was six fold with a subsurface spacing of 2.5 ft (0.8 m) for reflection points.

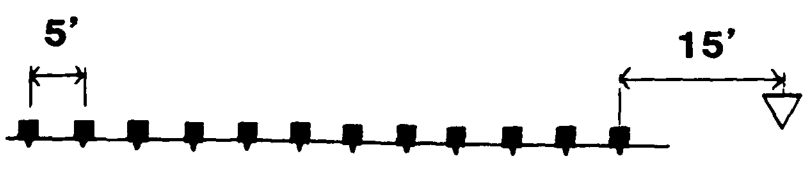


Figure 5. Shot, geophone layout for one shot record, Line C-2

Line C-3

23. Line C-3 was also an overlap of Line C-1 but from Flags C-194 through C-337 for a total line length of 715 ft (218 m). Line C-3 had the exact same target as Line C-1 and was acquired as a practically redundant data set. The principal difference was in the source and receivers used for the two lines. Line C-1 was a time-consuming and labor intensive effort with each geophone station requiring the planting of six evenly spaced geophones ($6 \times 24 = 144$ geophones per shot) and the shot requiring the augering of a hole and reloading the Buffalo Gun for three shots. The difference in data quality can be compared between such a painstaking approach with data acquisition and a quick and inexpensive approach. Therefore, the same offset, spread lengths, and instrumental parameters were used for Lines C-1 and C-3. Single, 100 Hz geophones were used in place of groups, however, and nine stacks of a sledgehammer on a steel plate replaced the Buffalo Gun. The two lines therefore had the same CDP coverage over a common 715 ft (218 m) length. But Line C-1 required 2 days to cover this length; Line C-3 covered it in less than 1 day.

Vertical Seismic Profiling Data

24. The original plan for our survey was to tie the reflection data to well data via vertical seismic profiling (VSP) in several of the test wells. These tests were not successful as all holes had caved or were at least bridged over at shallow depth such that the borehole seismometer could not be advanced. Hole BE-2 was closed 90 ft (27 m) depth; no other hole (BE-1, BE-3, or BE-4) was open as deep as 50 ft (15 m).

PART V: DATA PROCESSING

25. Lines C-1, C-2, and C-3 were initially processed in rough form on the ES-2420 field acquisition unit. The lines were then processed again using the state-of-the-art processing software available at Compagnie General de Geophysique (C.G.G.) American Services in Denver. Due to the limited use of seismic techniques for engineering projects, the two processing methods were to be compared for feasibility and quality versus cost.

26. The ES-2420 processing was limited to full trace filtering, normal moveout (NMO) at constant velocity, and CDP stack or gather. The processing possibilities at C.G.G. were virtually unlimited except by cost and time constraints.

ES-2420 Processing

27. Limited processing procedures are available on the ES-2420 including editing, NMO correction (at constant velocity), common offset gather, and CDP stack. All of the lines were initially processed on the ES-2420 as a preliminary product for inspection of data quality and for comparison with other processing systems. The total ES-2420 processing for the Beaver Dam data required little more than 1 week. Elevation statics were not applied (although the ES-2420 does have statics capabilities). The results were encouraging but by no means the best possible from the data set.

28. Lines C-1 and C-3 (see Figures 6 and 7) had obvious noise problems which are discussed in detail in subsequent sections in addition to statics problems. The ES-2420 cannot do deconvolution or time-variant filtering, which seemed to be necessary. In addition, variations in velocity, both lateral and with time, could not be accounted for by the ES-2420. Line C-2, on the other hand, could be processed satisfactorily using a single velocity function and thus was less affected by the restraints of the ES-2420. Generally, good results were obtained on Line C-2 by effectively eliminating traces contaminated by noise within the zone of interest while the processing of Lines C-1 and C-3 was far from satisfactory. Little improvement could be achieved on Line C-2 by further processing as explained later in the processing section.

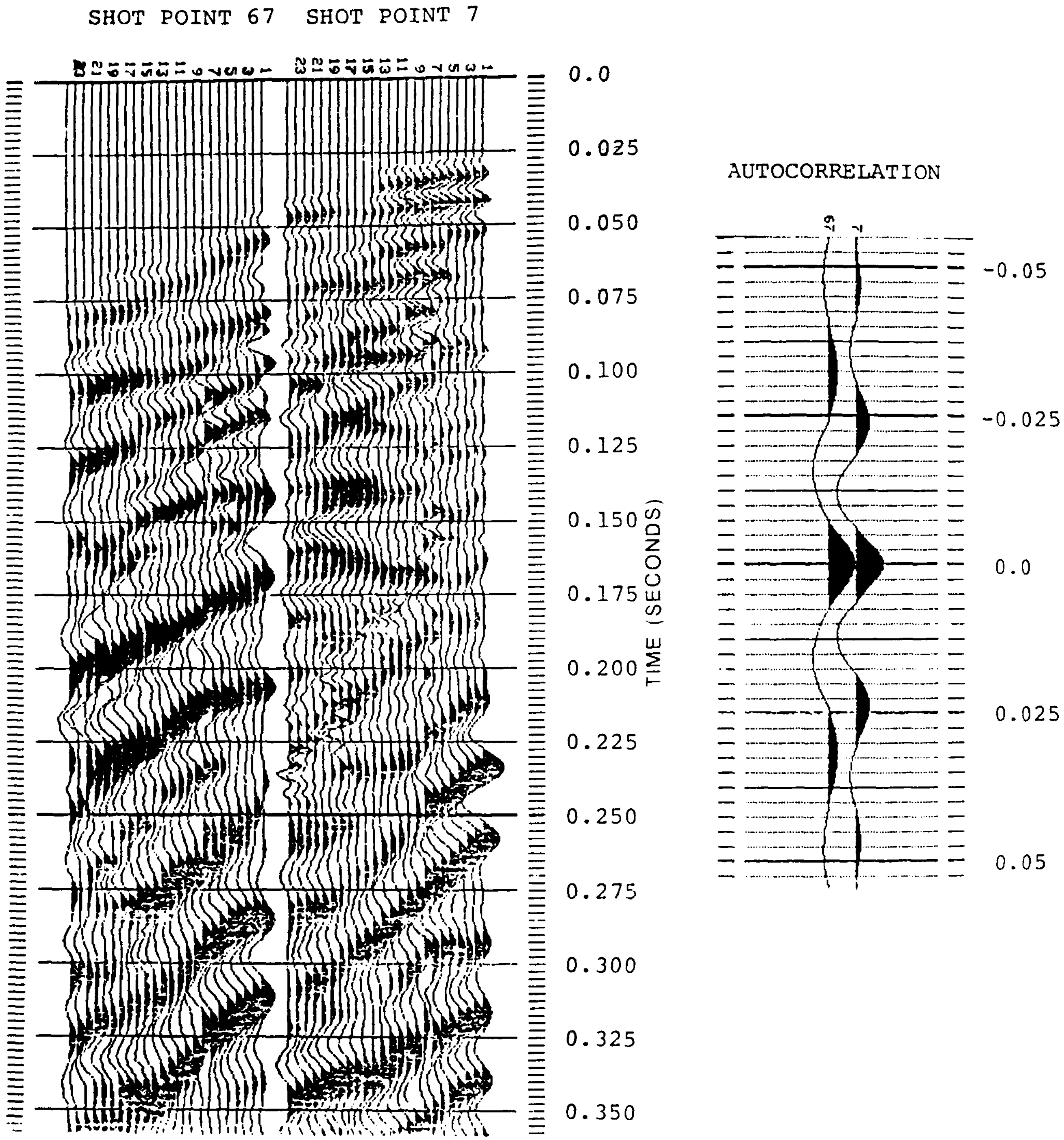
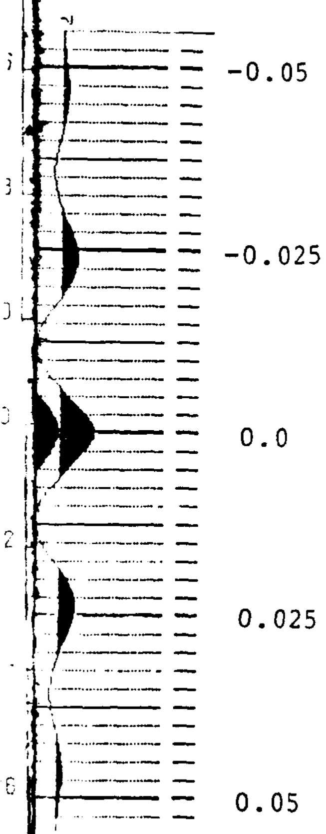
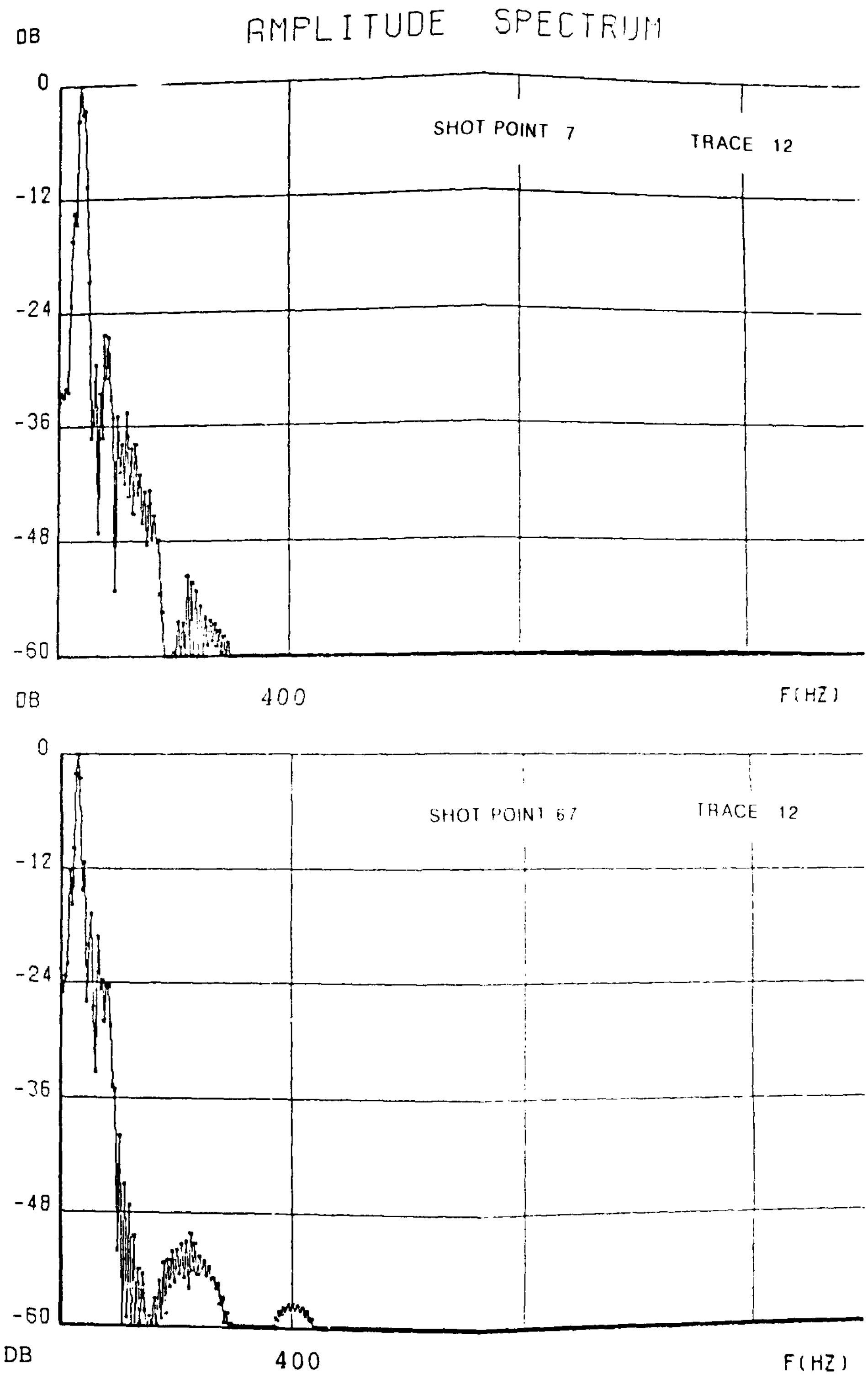


Figure 6. Beaver Dam, Line C-1, unfiltered record

RELATION





-1, unfiltered records

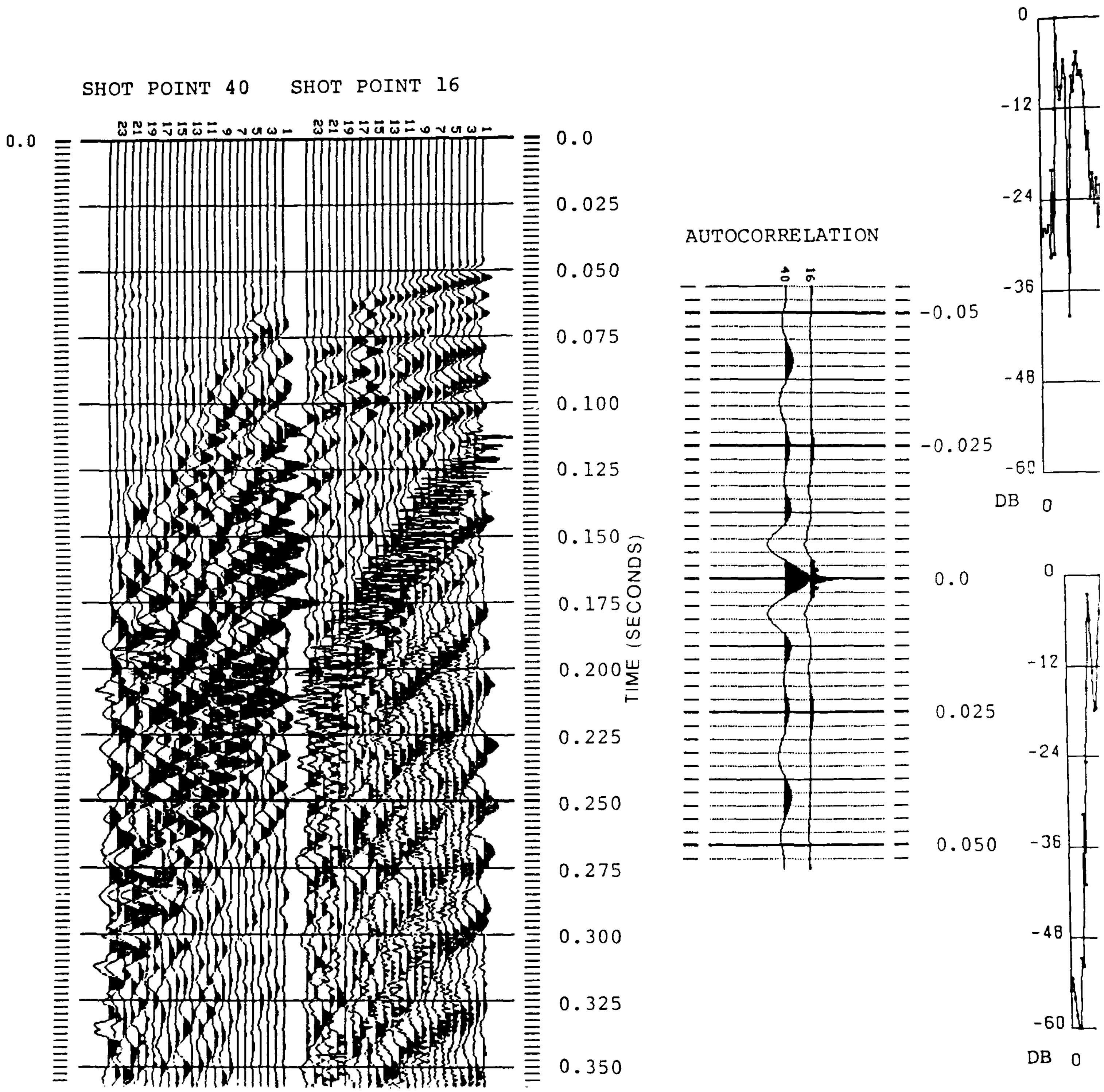
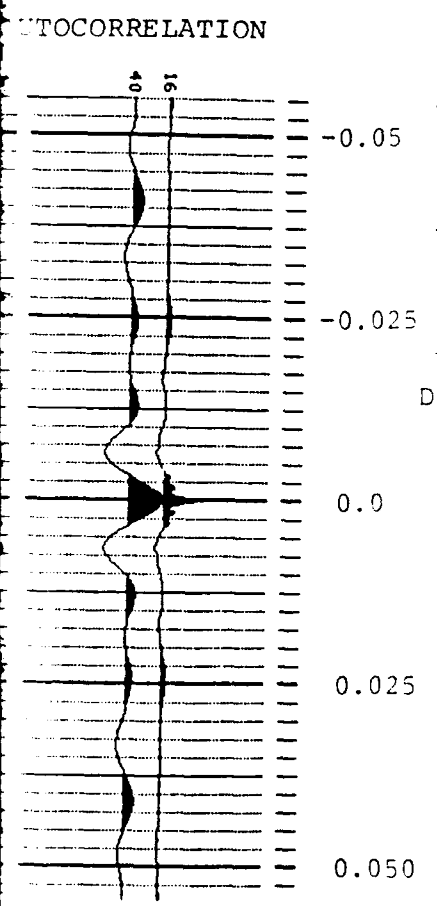
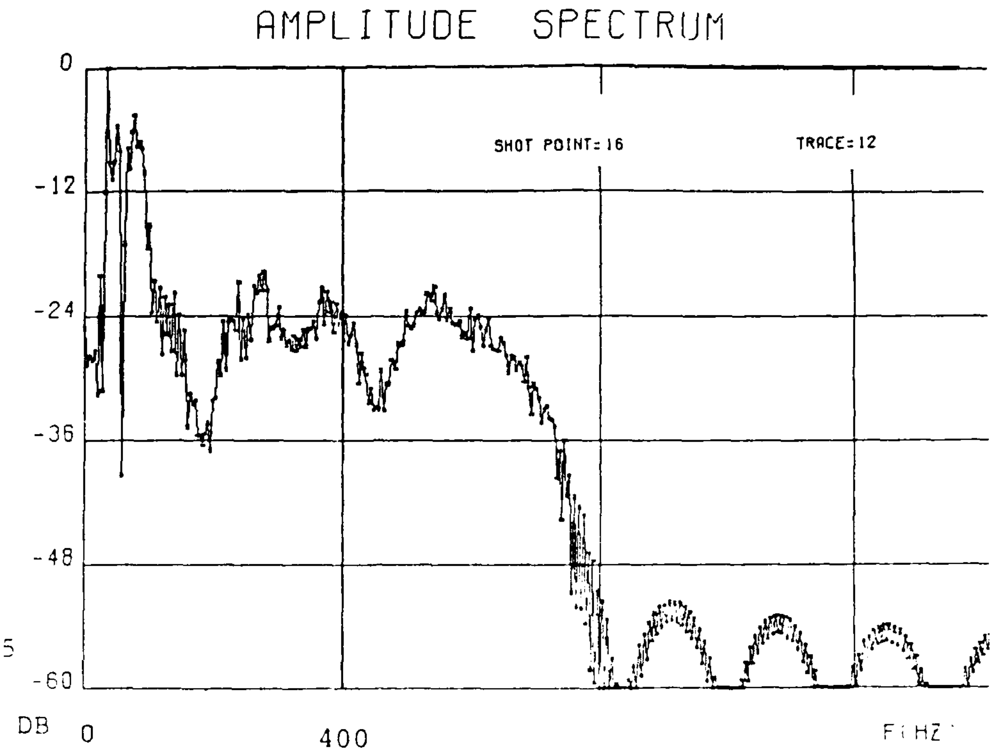
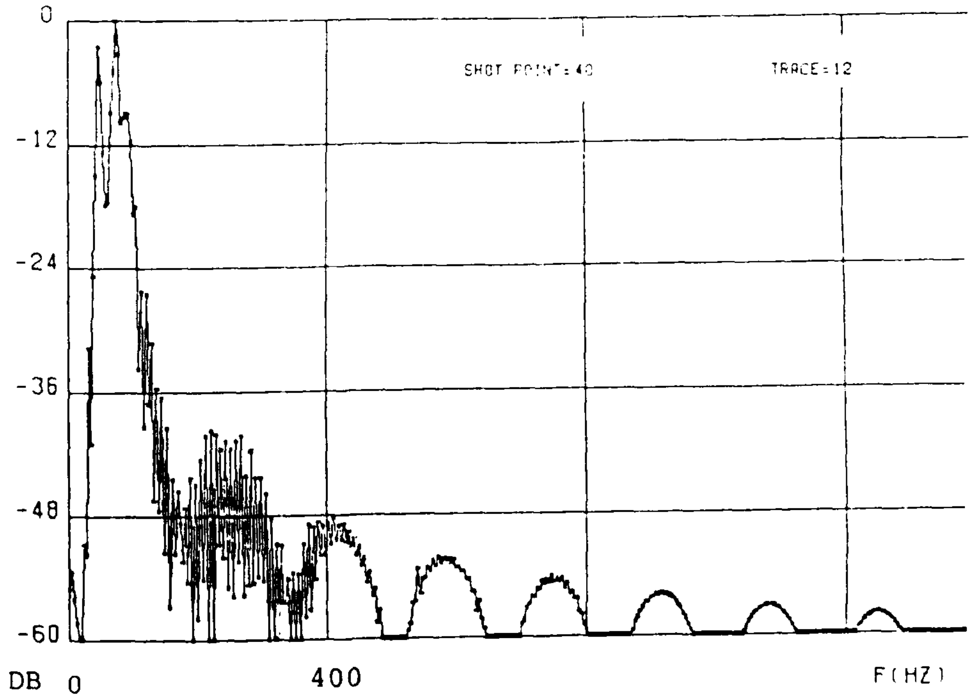


Figure 7. Beaver Dam, Line C-3, unfiltered records







r Dam, Line C-3, unfiltered records

29. The ES-2420 was a good processing tool because velocities and trace edits could be determined prior to the more expensive C.G.G. processing. This type of processing could be done in the field immediately after acquisition to determine any problems that could be corrected by changing field parameters.

C.G.G. (Lines C-1 and C-3) Processing

30. Lines C-1 and C-3 were intended to allow a direct comparison of the best result from the two distinctly different approaches to acquisition. The C.G.G. American Services Geomax software was used in an effort to give such shallow high-resolution methods a fair opportunity to be tested with state-of-the-art processing modules. The processing sequences for the two lines were made as parallel as possible for comparison purposes.

31. An outline of the processing sequence for Beaver Dam, Lines C-1 and C-3 are listed below.

a. Demultiplex and reformat.

b. Gain compensation for transmission loss and spherical divergence.

c. CDP sort.

d. Geophone edit.

e. Shot and trace edits.

f. Statics to flat datum.

g. Spiking deconvolution.

h. Operator length = 40 msec.

i. Window from 62.5 to 250 msec.

j. Automatic residual statics.

k. Velocity analysis.

l. NMO correction.

m. Mutes.

n. Automatic residual statics.

o. CDP stack.

p. Time variant band pass filtering, 72/88-240/280 Hz, T0 - T100 msec, 72/88-180/220 Hz, T150 - T500 msec.

q. Dynamic trace equalization.

r. Statics to floating datum (end point for final stack).

s. Wave equation migration.

t. Band pass filtering.

u. Dynamic trace equalization.

v. Film display.

32. The sequence is similar to a simple sequence for normal deep seismic processing but with some differences. The major problems with these two lines were:

a. Optimizing filters.

b. Removing airwave noise and groundroll.

c. Choosing velocity functions near surface.

d. Resolving statics.

33. One difficulty with the data acquired in engineering geophysics projects is that the acquisition methods differ radically from normal deep seismic reflection data acquisition. The high-resolution data are often recorded at fractional sample rates such as 0.25 msec. Also, the data lengths are typically very short, such as 500 msec. Although this might not seem to be a problem, it can be when processing with software tailored to normal seismic reflection acquisition parameters. Many processing packages cannot handle decimal sample rates as in this Arkansas project; therefore, the headers had to be changed on an alternate computer (a Raytheon) to "fool" the system into believing that the sample interval was 1 msec with a data length of 2,000 msec instead of 500 msec. All subsequent processing was then done as if the data were 2,000 msec. Velocities and frequencies, entered as one-quarter of their real values, had to be converted back to real values before analysis. The short data lengths were also a problem in some cases. Line C-2, which had a data length of only 200 msec (800 msec in processing time), had problems in filtering solely because the application window of the filters for optimum efficiency was nearly as long as the whole data set and, in some cases, longer for the lower frequencies.

34. Extensive testing was deemed necessary to resolve these problems, particularly because high-resolution shallow seismic data processing has been relatively unexplored.

Filtering

35. Both of these lines had 25 Hz high pass field filters. Figures 6 and 7 show the amplitude spectrum, autocorrelation, and a pair of raw records from each line. The data are dominated by low-frequency groundroll (Rayleigh surface waves) and high-frequency airwave. More airwave was experienced where

shooting over hard ground occurred because deep holes could not be drilled. A low cut of 36 Hz and a high cut of 280 Hz were used on the data, as suggested by a harmonic filter test. Both lines were improved, but a bad data zone still resulted from the airwave and groundroll, particularly on Line C-1. It was hoped that an F-K velocity filter would eliminate the noise without removing reflection data within the upper frequency range. While the airwave was obviously slower velocity than any data, this method proved to be fruitless due to the fact that the frequency of the noise was very high. Thus, when transformed to the F-K domain, the wave number over which the filter was applied corresponded to a frequency which was far below that of the noise. This type of filter works much better on noise that is low frequency as well as low velocity such as groundroll. The only alternative was to lower the high- and low-cut frequency and use that to reduce the frequency content of the data. Figures 8 and 9 show the final filtered records and their amplitude spectra. The bulk of the amplitude spectra lost at high-frequency noise. These were the final filters used on these data.

Velocity analysis

36. Near surface reflections were very sensitive to velocity change while deeper events (> than 100 msec) were completely insensitive to change because their moveout is nearly flat for such short spread lengths. Unfortunately, slight changes in the velocity of shallow reflections change their character but do not identify necessarily which velocity is correct. The lateral velocity variation reflects the boundaries of the graben and the vuggier zone between them.

Deconvolution

37. A spiking deconvolution was used to collapse the wavelet using an operator length of 120 msec. Several operator lengths and white noise levels were tested. The data were rather steady state in quality once a length of 120 msec was reached; therefore, while deconvolution is necessary, little testing is necessary. A medium length operator used in a spiking deconvolution routine with about 1 percent white noise should be sufficient as long as an impulsive source is used.

Statics

38. Near surface problems, including those created by fault zones, had to be resolved on these lines. Two passes of surface consistent of short wavelength automatic statics were run to resolve problems created by

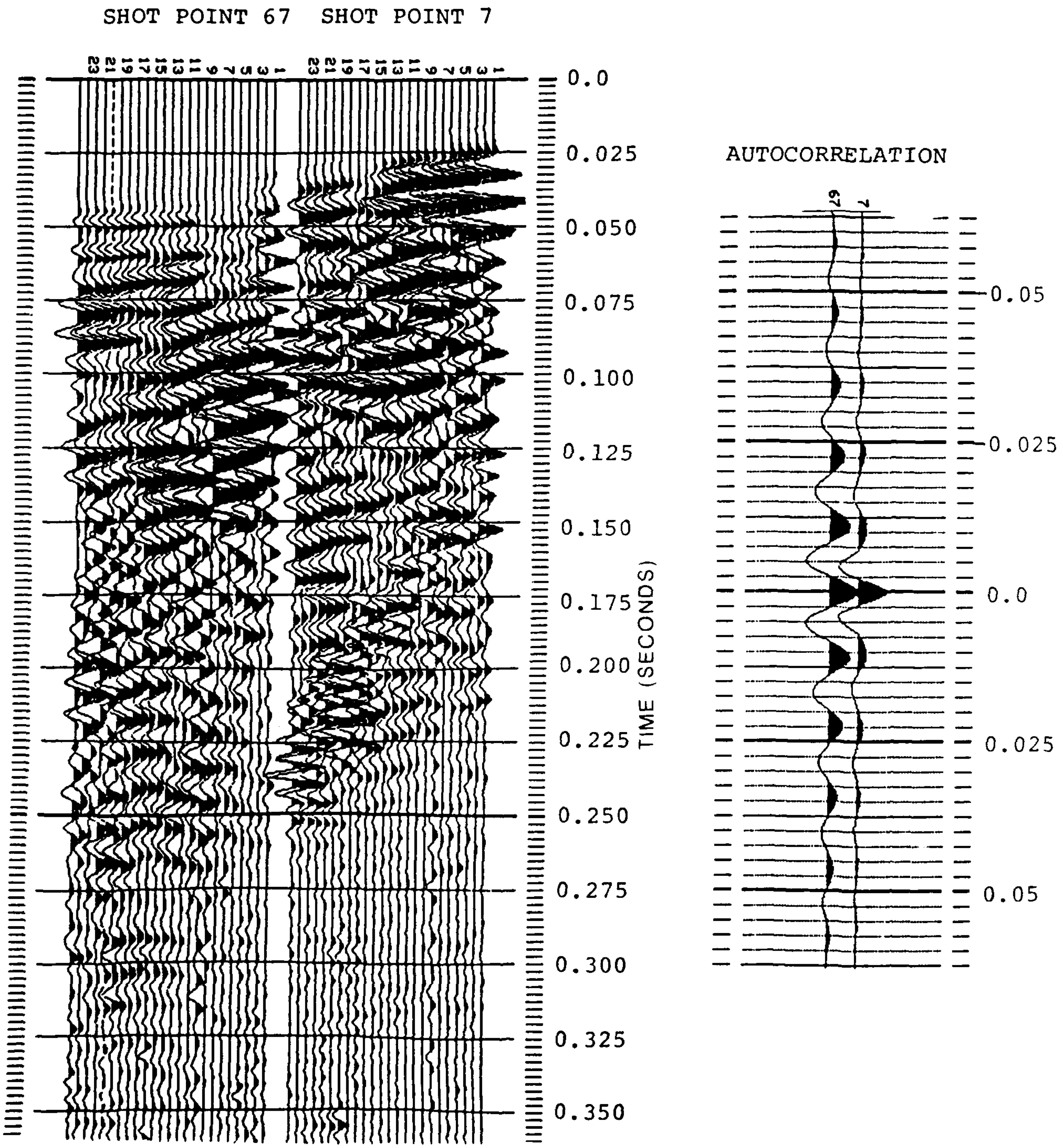
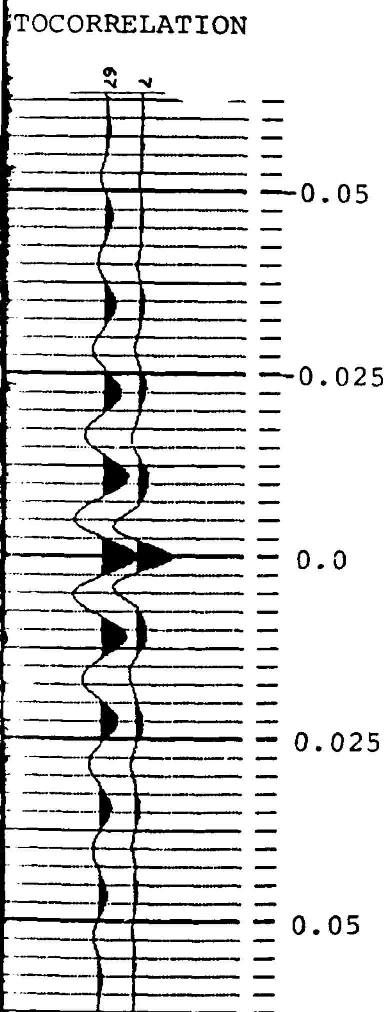
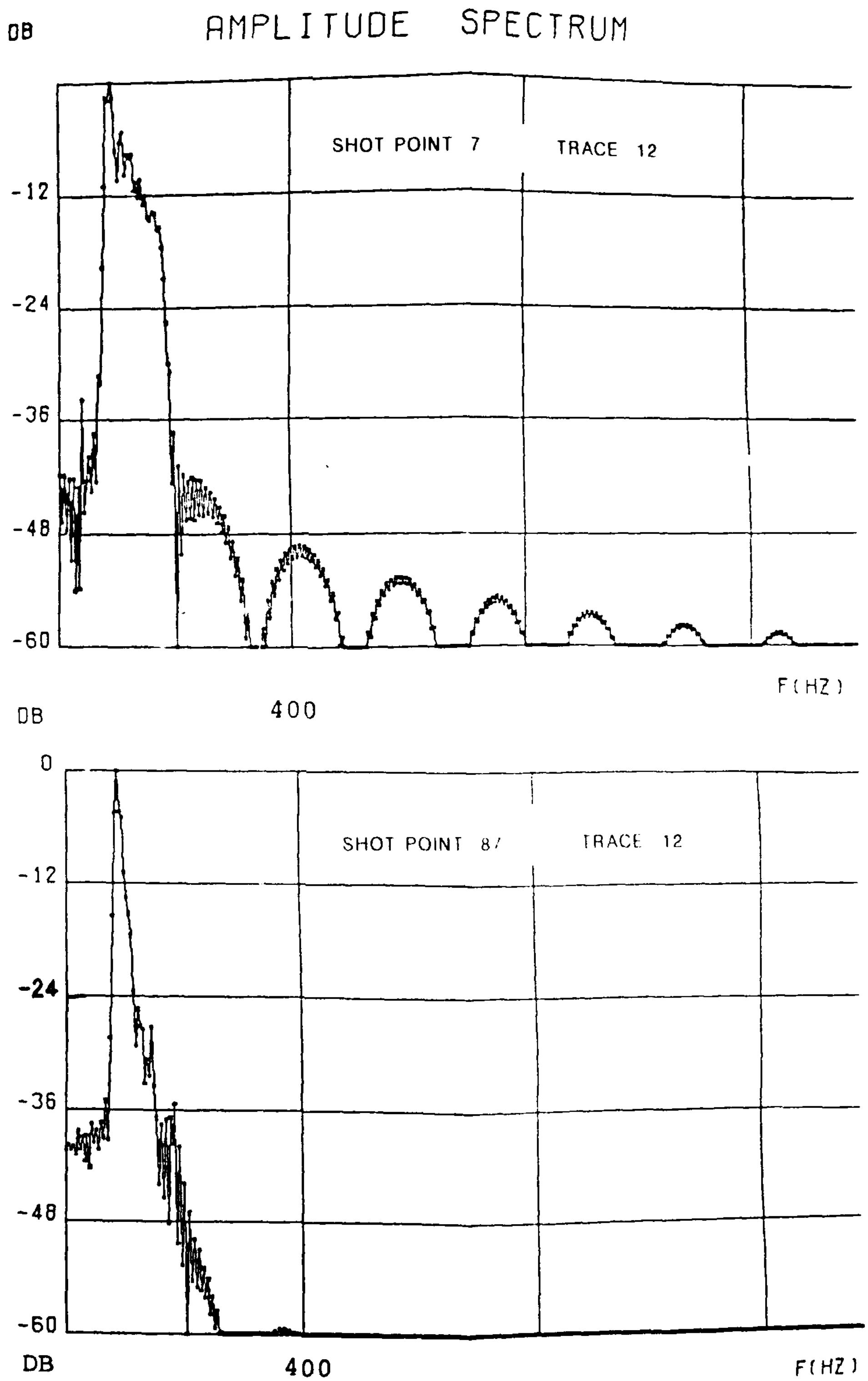


Figure 8. Beaver Dam, Line C-1, time-variant filtered re





Line C-1, time-variant filtered records

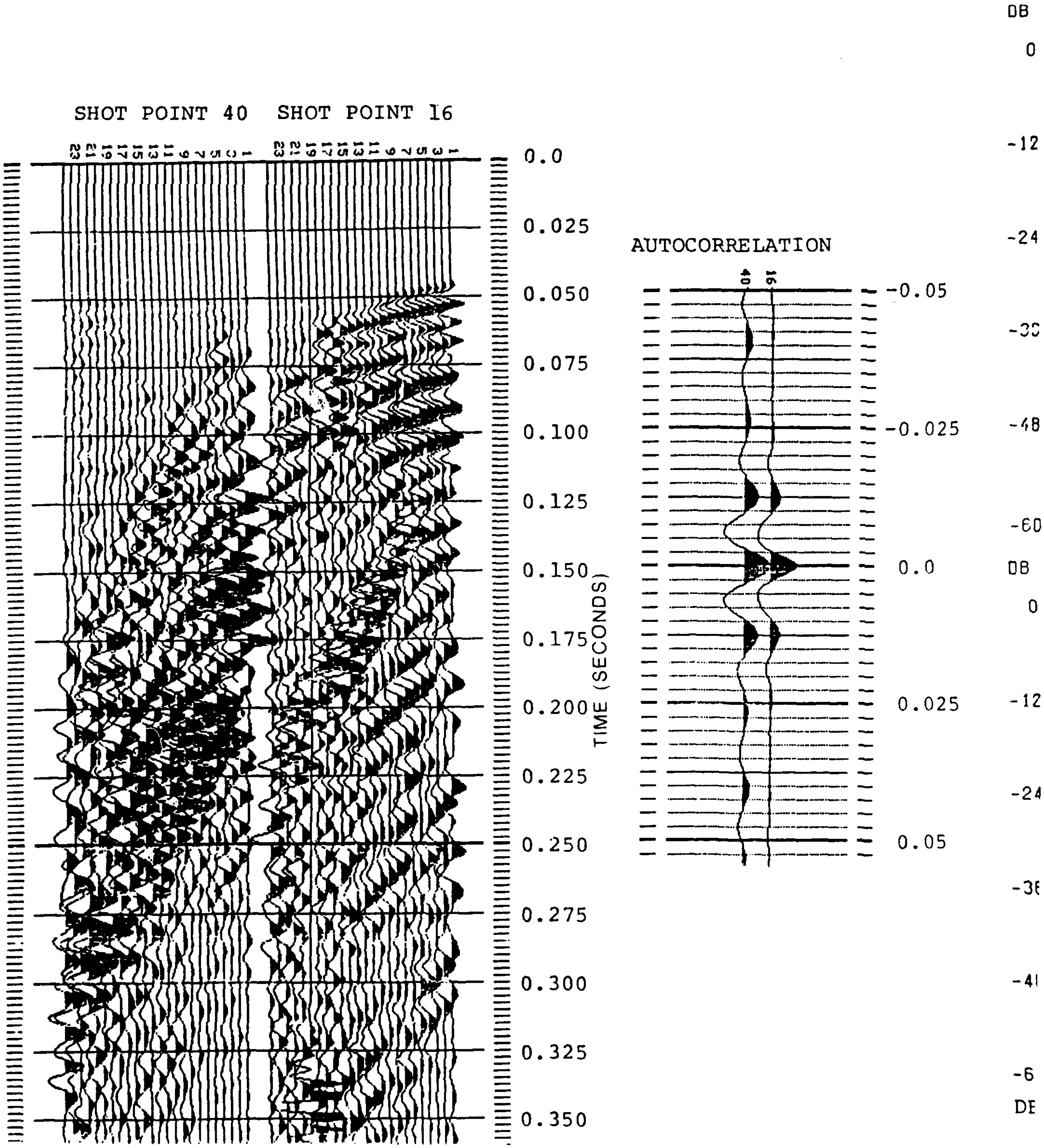
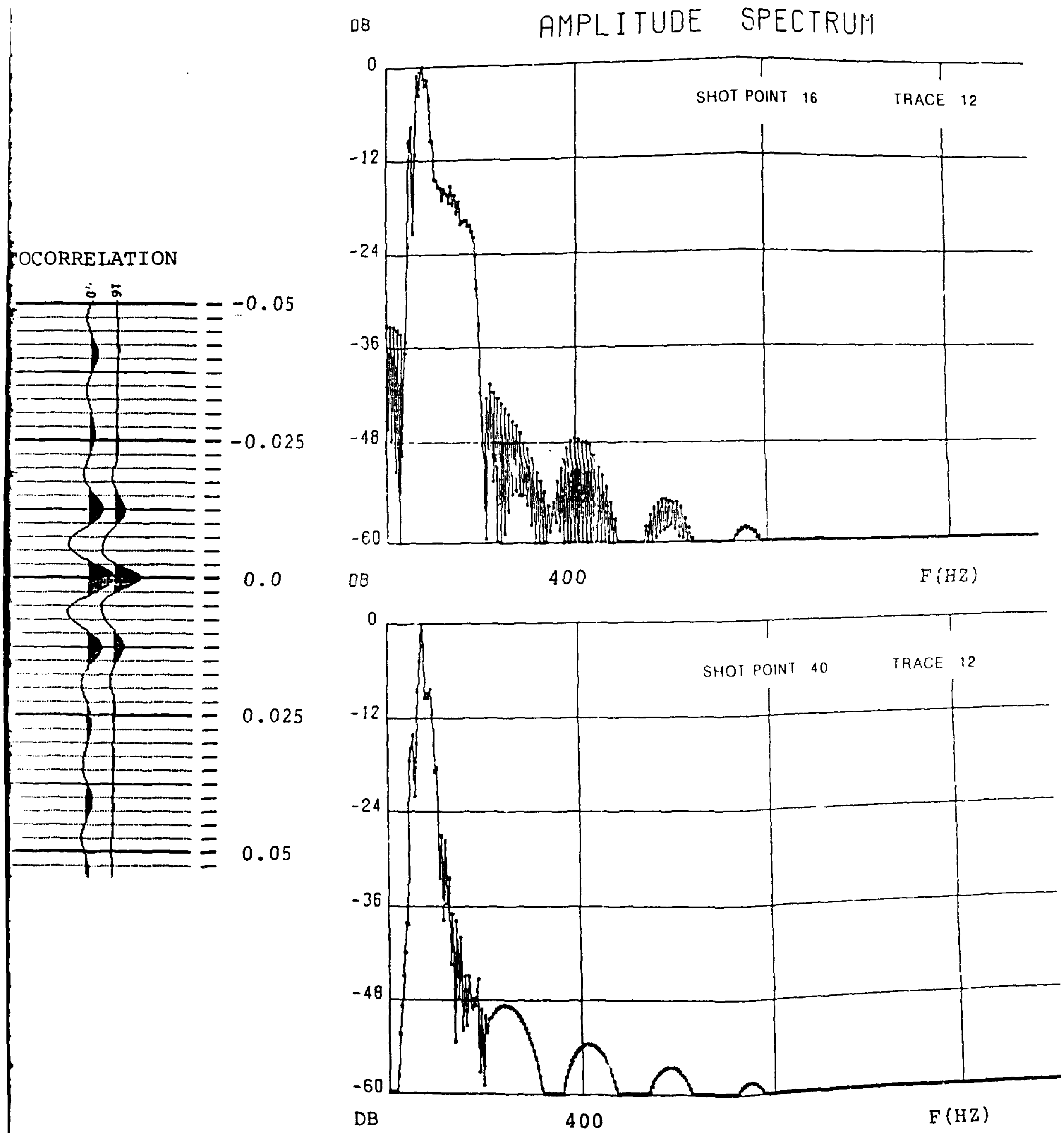


Figure 9. Beaver Dam, Line C-3, filtered record



er Dam, Line C-3, filtered records

perturbations in the weathered zone. This was particularly important since elevations were not surveyed. Elevations were hand picked from topographic maps and from elevations of piezometers spaced along the line. Future engineering projects would likely benefit from accurately surveyed elevations and station locations. Elevations in this case were probably within tolerances of 1/2 ft (0.15 m). In addition, weathering velocities are well known based on refraction surveys; thus, datum statics are probably very good. Correct weathering velocity is crucial for shallow reflection surveys to the extent that, if necessary, reconnaissance drilling or seismic refraction surveys should be commonplace before such work to avoid large errors in datum statics.

Migration

39. Although sedimentary dip was not really a problem at the Beaver Dam site, migration was deemed necessary to collapse any diffractions from fault planes. A wave equation migration routine was tested beginning with values recommended for traditional seismic work and adjusted from that point. Several combinations of downward continuation step size and velocity function were tested. While the data were somewhat sensitive to velocity, the most critical value was the increment for each downward continuation iteration. Due to the frequencies and times involved in these data, the step had to be smaller than normally used even in steeply dipping areas. The best migration obtainable within the time frame available to use was achieved at 90 percent stacking velocities with an increment of about 6 msec per downward continuation iteration.

40. Further investigation of migration for shallow high-resolution seismic data is needed. It is possible that other migration methods such as finite difference migration or partial or full prestack migration might be a better method for these data. These methods were not tried in this study due to time constraints.

C.G.G. (Line C-2) Processing

41. Line C-2 was shot expressly for the purpose of examining the near surface, or more specifically, the weathered layer/rock interface. Additional processing (over that done on ES-2420) was limited to filtering, very minimal muting, constant velocity moveout, and stack. Deconvolution was abandoned because the low signal to noise ratio would not allow the filter to

stabilize. Data were not corrected for statics other than datum statics. In this case, the ES-2420 processing was probably sufficient, in fact better than the more expensive option. This was mainly in light of the fact that the SEGD tapes had header errors that would not allow C.G.G. to read all of the records making this data set incomplete.

Data Quality and Cost Comparison (ES-2420 versus C.G.G.)

42. Lines C-1 and C-3 were most obviously improved by the additional processing at C.G.G. Figure 10 (with the ES-2420 section of Line C-1 on the left and the C.G.G. processed section on the right) illustrates the character differences between the two methods. Time scales are similar; the C.G.G. horizontal scale is about one-half the ES-2420. Most obvious differences are frequency content (ES-2420 dominated by groundroll), C.G.G. migration eliminating the large diffraction (at 75 on ES-2420), and better definition of faults on the C.G.G. section. The more advanced processing techniques improved the frequency content of the data by about 130 Hz. Most likely, the capability of using multiple, time-variant velocity functions can be credited with the drastically improved frequency of the data. On Line C-1, time-variant filtering reduced airwave noise without diminishing the data quality.

43. Continuity was improved by static corrections, thus emphasizing the fault zones. Time and space variant velocities also improved the continuity of the data on both Lines C-1 and C-3 to well beyond that achieved on the ES-2420.

44. On Line C-2, the different processing methods made a minimal difference. It is possible that for weathered zone surveys, field processing may be sufficient, mostly because constant velocity functions can be used. However, on these shallow surveys, correct elevations are most critical and should be incorporated via datum statics application (available on ES-2420, but not used in this example).

45. In terms of cost, processing on the ES-2420 involved about 2 weeks rental cost or about 7,000 dollars, which is about 6 dollars per stacked trace on Line C-1. The processing at C.G.G., which is probably representative of computer time cost at any data processing service company, came to about 7,000 dollars including filming and copies. For the processing alone, this amounts to about 7 dollars per stacked trace on Line C-1.

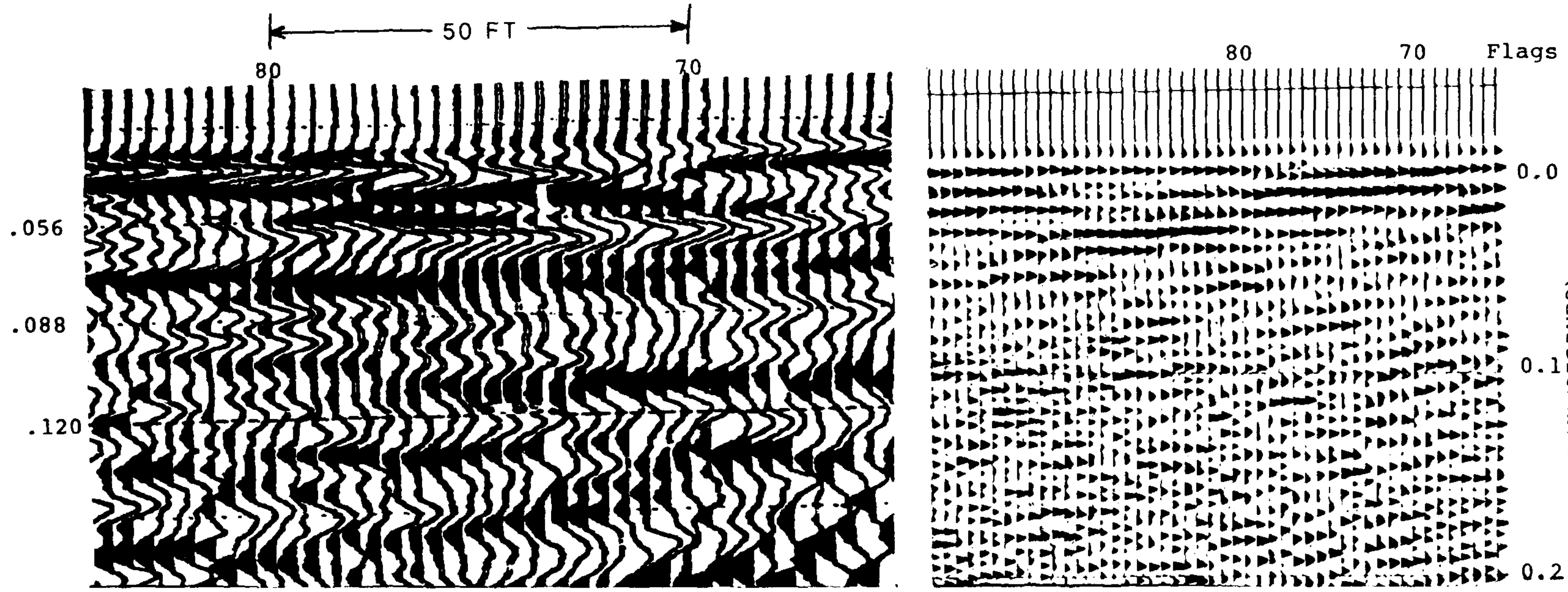


Figure 10. Comparison of ES-2420 processing (left) with C.G.G. processing (right) for a small portion of seismic Line C-1, Beaver Dam

46. If the ES-2420 is owned and is required in any case for data acquisition, its incremental processing cost is limited only to operator time. If ultimate resolution of deeper structure is a survey requirement, then the cost of outside, sophisticated processing is justified. For most surveys involving structural interpretation within the upper 200 to 300 ft (61 to 91 m), the ES-2420 processing itself can give rapid and useful sections for interpretation.

47. Relating this back to compatibility with WES seismograph systems, it is apparent that the capability of doing shallow reflection analysis (as with Line C-2) is possible because some microcomputer-based software can be purchased or written which will mimic the ES-2420 capability. The deeper investigations would be at a severe disadvantage unless data can be transferred to tape in a standard SEG format for advanced processing.

PART VI: GEOLOGICAL INTERPRETATION

Deep Basement Structure

48. Line C-1 was surveyed to look specifically at deep structure (faults) affecting the dike. Figure 11 presents reduced and interpreted CDP stacked sections along Line C-1. The sections presented are the final CDP stack and a migrated stack section. Full-sized and noninterpreted versions of Figure 11 are included as Plates 1 and 2. The colored bands were chosen to represent continuous reflections and, because of no available well control, are not tied to specific stratigraphic horizons. The continuous strong reflection along the central portion of the line represents the Chattanooga/Sylamore sequence.

49. The key observation along this line is the evident and substantial faulting. The known major north and south bounding faults are actually series of faults of rather complex character. In addition, there are several observed faults within the graben which had not been noted in the drilling program. Using Line C-1, the positions of all faults were located and thereby transferred onto the section from Line C-2 which only looked at shallow horizons.

50. The large boundary faults of the graben were previously interpreted from borings and other geophysical methods. Plan maps showing locations of boreholes are in US Army Corps of Engineers (1986) and Llopis and Butler (1988). Borehole locations along the C-line are indicated on the seismic sections. These faults are located near boreholes B27.9 on the North, and G29.3 on the South. Other faults exist in the graben at sta 301 to 321 (Flags 166 to 176) and between sta 351 to 371 (Flags 191 to 201). The faults are indicated by disruptions in continuity of events, changes in wave form, and offsets in events. The throw on these faults within the large graben is probably small, but it is likely that these zones of weakness are prone to leakage through the foundation.

The Weathering Layer

51. Figure 12 is a CDP stacked section along Line C-2. It is plotted in reverse direction from Line C-1 because it was processed only by the

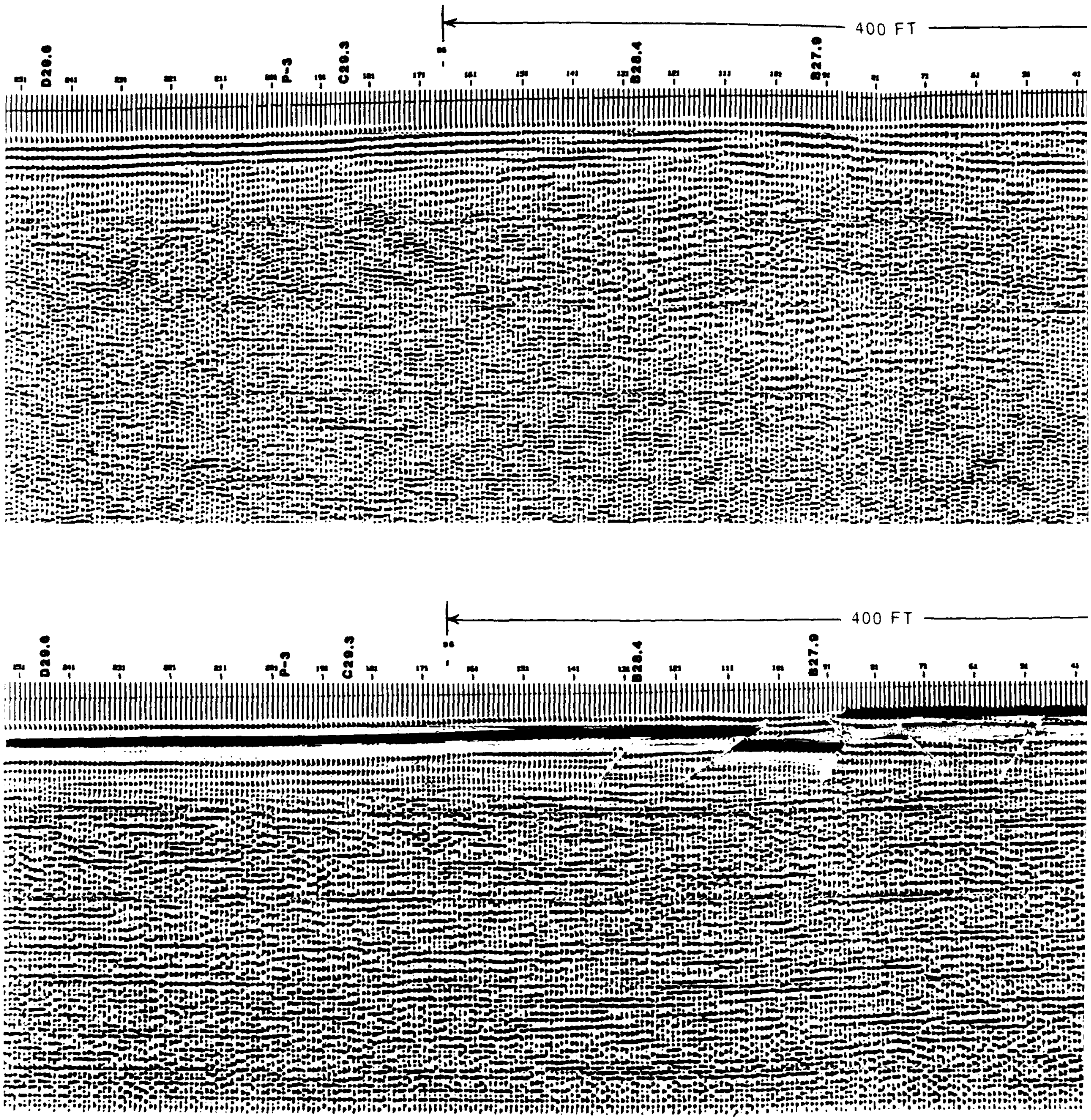
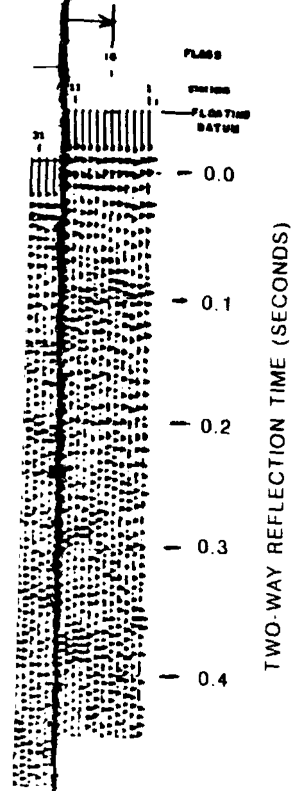


Figure 11. CDP sections (upper is final stac
from Line C-1, Beaver Dam



COMPUTING

COMPUTED AT CGG DATA PROCESSING CENTER
1616 CHAMPA ST., DENVER COLORADO
DATUM PLANE: 1000 FT. CORRECTIONAL VELOCITY: 2000 FT./SEC.

GEOMASTER PROCESSING SEQUENCE

01-DEMULTIPLEX
02-GAIN COMPENSATION FOR TRANSMISSION LOSS AND SPHERICAL DIVERGENCE
03-CDP SORT
04-GEOPHONE EDITS
05-SHOT AND TRACE EDITS
07-STATICS TO FLAT DATUM
08-SPIKING DECONVOLUTION
OPERATOR LENGTH 40 MSEC.
WINDOW FROM 62.5 TO 250 MSEC.
09-AUTOMATIC RESIDUAL STATICS
10-VELOCITY ANALYSIS
11-NMO CORRECTION
12-MUTES
13-AUTOMATIC RESIDUAL STATICS
14-CDP STACK
15-TIME VARIANT BAND PASS FILTER
72/80-240/280 HZ. TO-1100 MSEC.
72/80-180/220 HZ. 1150-1500 MSEC.
16-DYNAMIC TRACE EQUALIZATION
17-STATICS TO FLOATING DATUM
18-FILM DISPLAY

DISPLAY PARAMETERS

HORIZONTAL SCALE: 12 TRACES PER INCH
VERTICAL SCALE: 14 INCHES PER SECOND
POLARITY: FIELD POLARITY

QUALITY CONTROL

DATE NOVEMBER 1986
CGG ACCT. NO.: 4223101
PROCESSED BY: TAMMA MUELLER
CHECKED BY: DR. T.L. DOBECKI
MONROE G. SAVAGE

SCALE

WATERWAYS EXPERIMENT STATION

COMPANY

BEAVER DAM ARKANSAS

AREA

LINE C-1

LINE

644 1

STATIONS

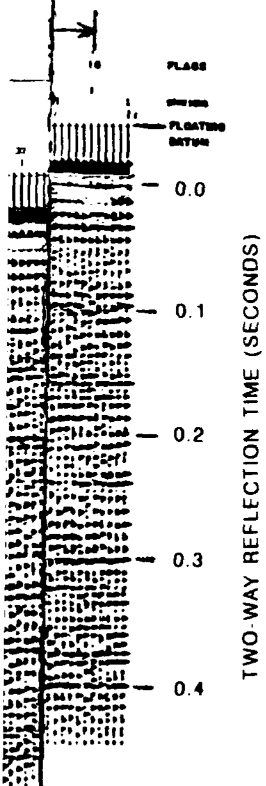
SOUTH NORTH

FINAL EQUALIZED STACK

FIELD RECORDING

RECORDED BY: CSM CREW
FIELD SYSTEM: ES-2420
ENERGY SOURCE: BUFFALO GUN
NO. OF SHOTS/HOLE: 3
GROUP INTERVAL: 5 FT.
NUMBER OF GROUPS: 24
GEOPHONE TYPE: GSC-20D
GEOPHONE ARRAY: 25 FT.
RECORDING FILTERS: LC: 25 HZ
HC: 780 HZ
NOTCH: 60 HZ

DATE: AUGUST 1986
FORMAT: SEGD
SAMPLE INTERVAL: .25 MSEC.
RECORD LENGTH: .5 SEC.
FOLD: 6
SHOTPOINT INTERVAL: 10 FT.
GEOPHONE FREQUENCY: 8 HZ.
GEOPHONE SPACING: 5 FT.
SLOPE: 18 DB/OCT
SLOPE: 18 DB/OCT



COMPUTING

COMPUTED AT CGG DATA PROCESSING CENTER
1616 CHAMPA ST., DENVER COLORADO
DATUM PLANE: 1000 FT. CORRECTIONAL VELOCITY: 2000 FT./SEC.

GEOMASTER PROCESSING SEQUENCE

01-DEMULTIPLEX
02-GAIN COMPENSATION FOR TRANSMISSION LOSS AND SPHERICAL DIVERGENCE
03-CDP SORT
04-GEOPHONE EDITS
05-SHOT AND TRACE EDITS
07-STATICS TO FLAT DATUM
08-SPIKING DECONVOLUTION
OPERATOR LENGTH 40 MSEC.
WINDOW FROM 62.5 TO 250 MSEC.
09-AUTOMATIC RESIDUAL STATICS
10-VELOCITY ANALYSIS
11-NMO CORRECTION
12-MUTES
13-AUTOMATIC RESIDUAL STATICS
14-CDP STACK
15-TIME VARIANT BAND PASS FILTER
72/80-240/280 HZ. TO-1100 MSEC.
72/80-180/220 HZ. 1150-1500 MSEC.
16-DYNAMIC TRACE EQUALIZATION
17-STATICS TO FLOATING DATUM
18-WAVE EQUATION MIGRATION
19-BAND PASS FILTER
20-DYNAMIC TRACE EQUALIZATION
21-FILM DISPLAY

DISPLAY PARAMETERS

HORIZONTAL SCALE: 12 TRACES PER INCH
VERTICAL SCALE: 14 INCHES PER SECOND
POLARITY: FIELD POLARITY

QUALITY CONTROL

DATE NOVEMBER 1986
CGG ACCT. NO.: 4223101
PROCESSED BY: TAMMA MUELLER
CHECKED BY: DR. T.L. DOBECKI
MONROE G. SAVAGE

SCALE

WATERWAYS EXPERIMENT STATION

COMPANY

BEAVER DAM ARKANSAS

AREA

LINE C-1

LINE

644 1

STATIONS

SOUTH NORTH

WAVE EQUATION MIGRATION

FIELD RECORDING

RECORDED BY: CSM CREW
FIELD SYSTEM: ES-2420
ENERGY SOURCE: BUFFALO GUN
NO. OF SHOTS/HOLE: 3
GROUP INTERVAL: 5 FT.
NUMBER OF GROUPS: 24
GEOPHONE TYPE: GSC-20D
GEOPHONE ARRAY: 25 FT.
RECORDING FILTERS: LC: 25 HZ
HC: 780 HZ
NOTCH: 60 HZ

DATE: AUGUST 1986
FORMAT: SEGD
SAMPLE INTERVAL: .25 MSEC.
RECORD LENGTH: .5 SEC.
FOLD: 6
SHOTPOINT INTERVAL: 10 FT.
GEOPHONE FREQUENCY: 8 HZ.
GEOPHONE SPACING: 5 FT.
SLOPE: 18 DB/OCT
SLOPE: 18 DB/OCT

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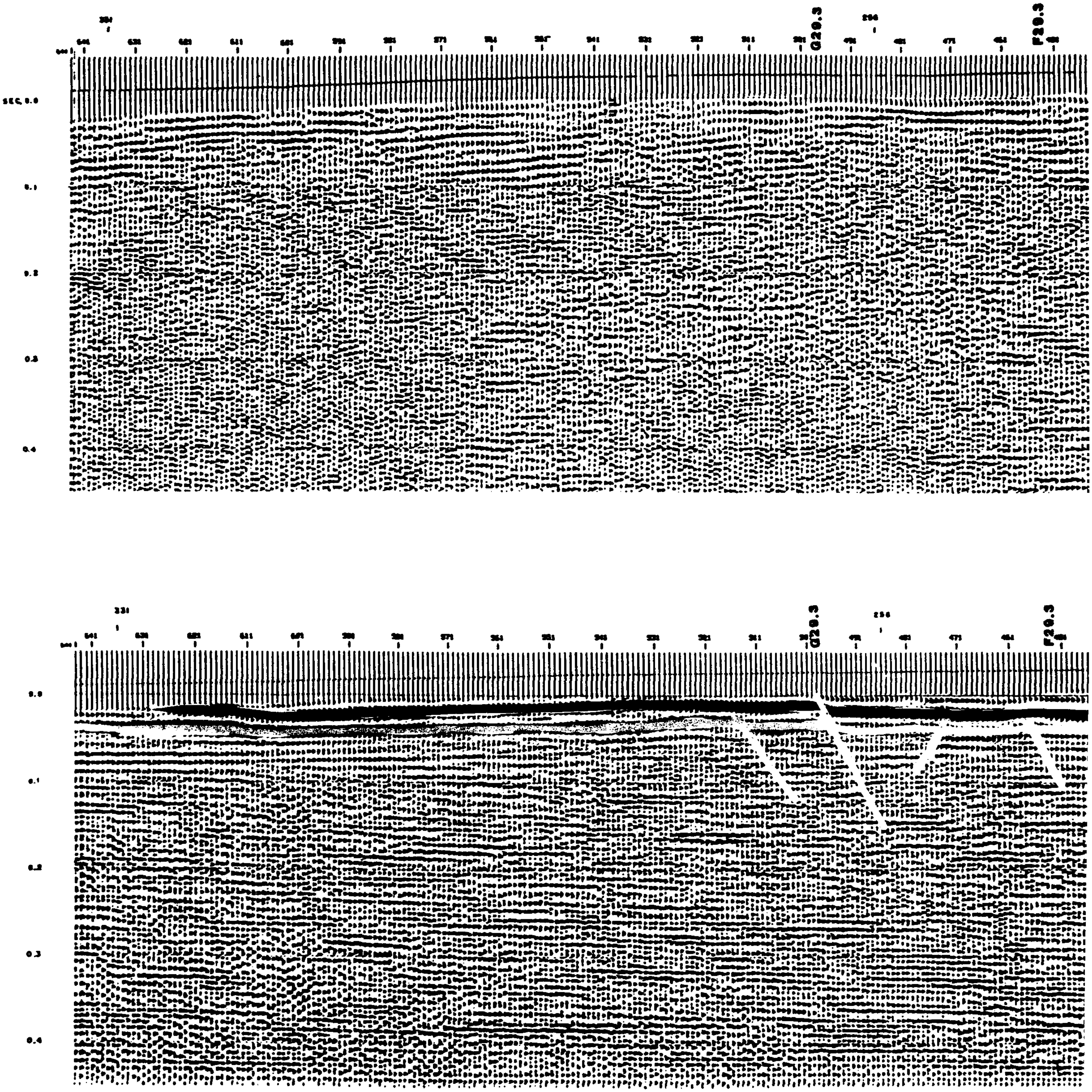
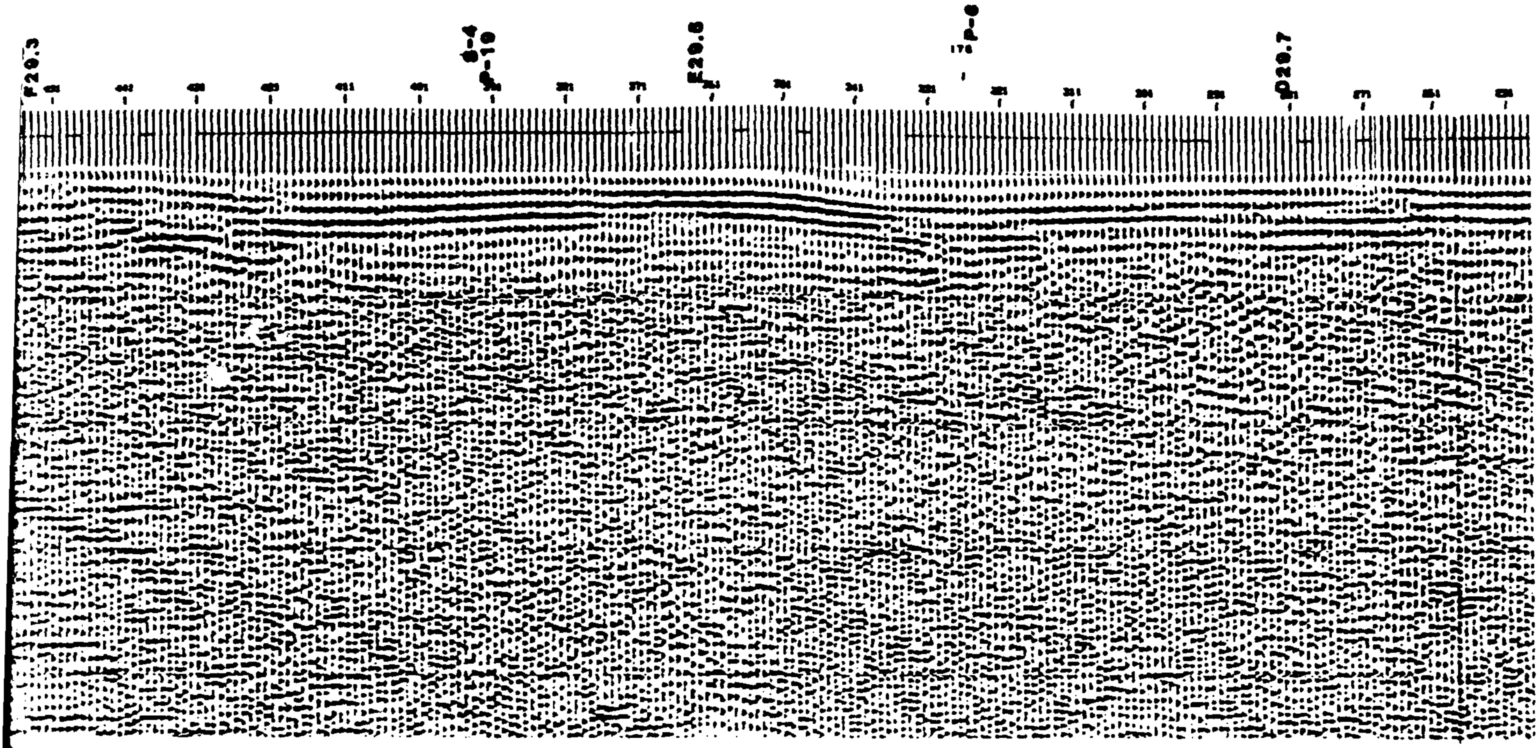
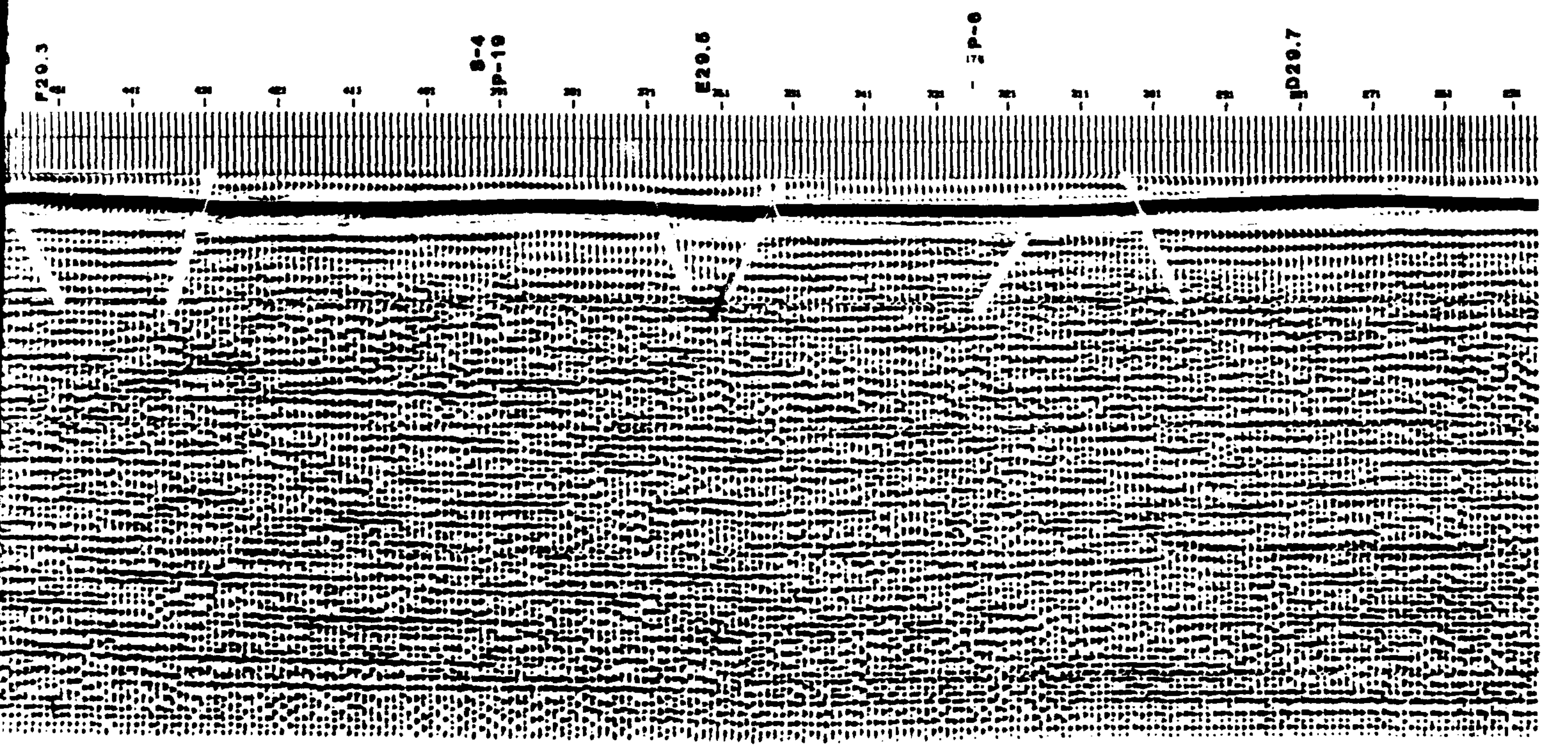


Figure 11. (Co





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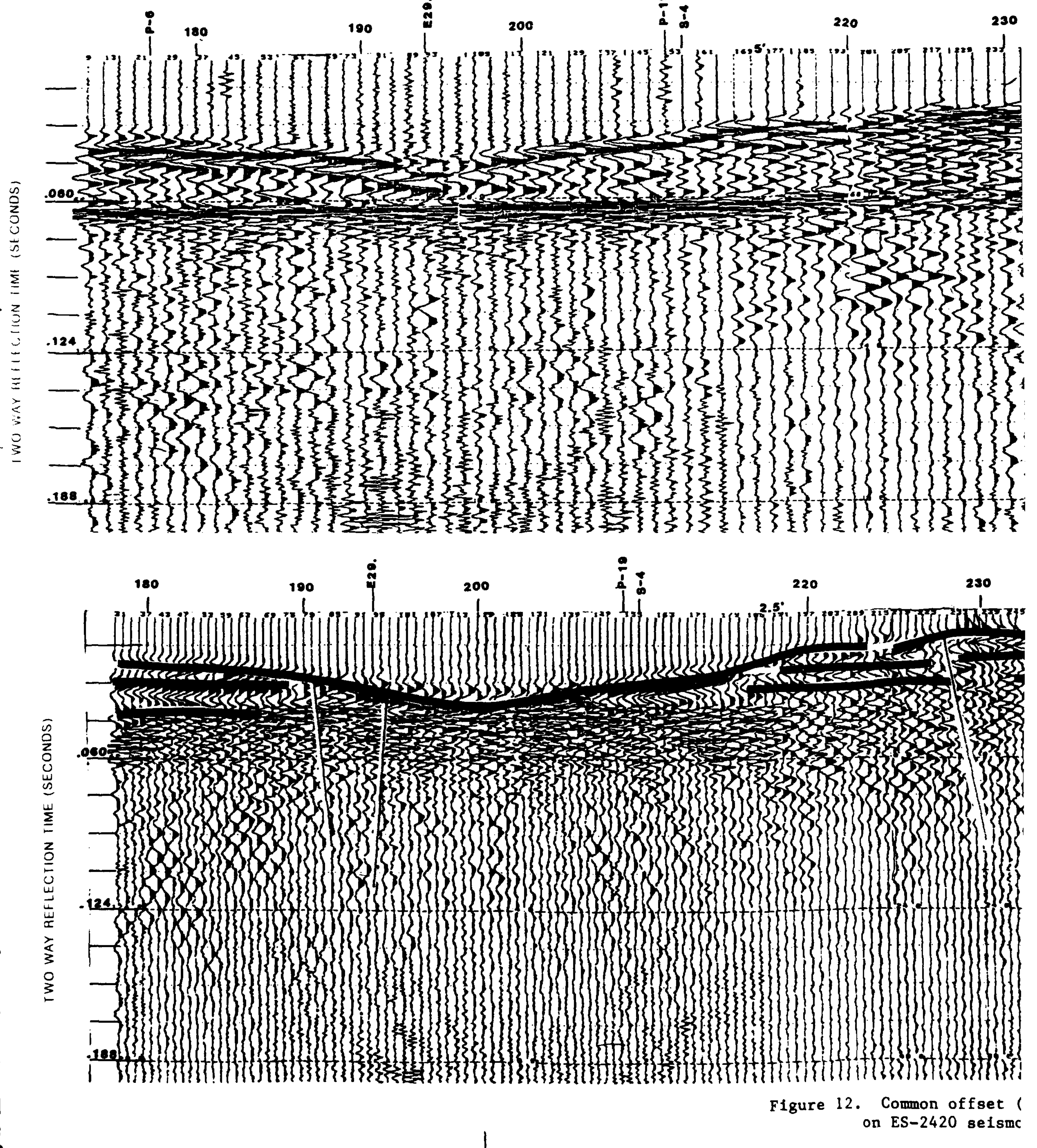
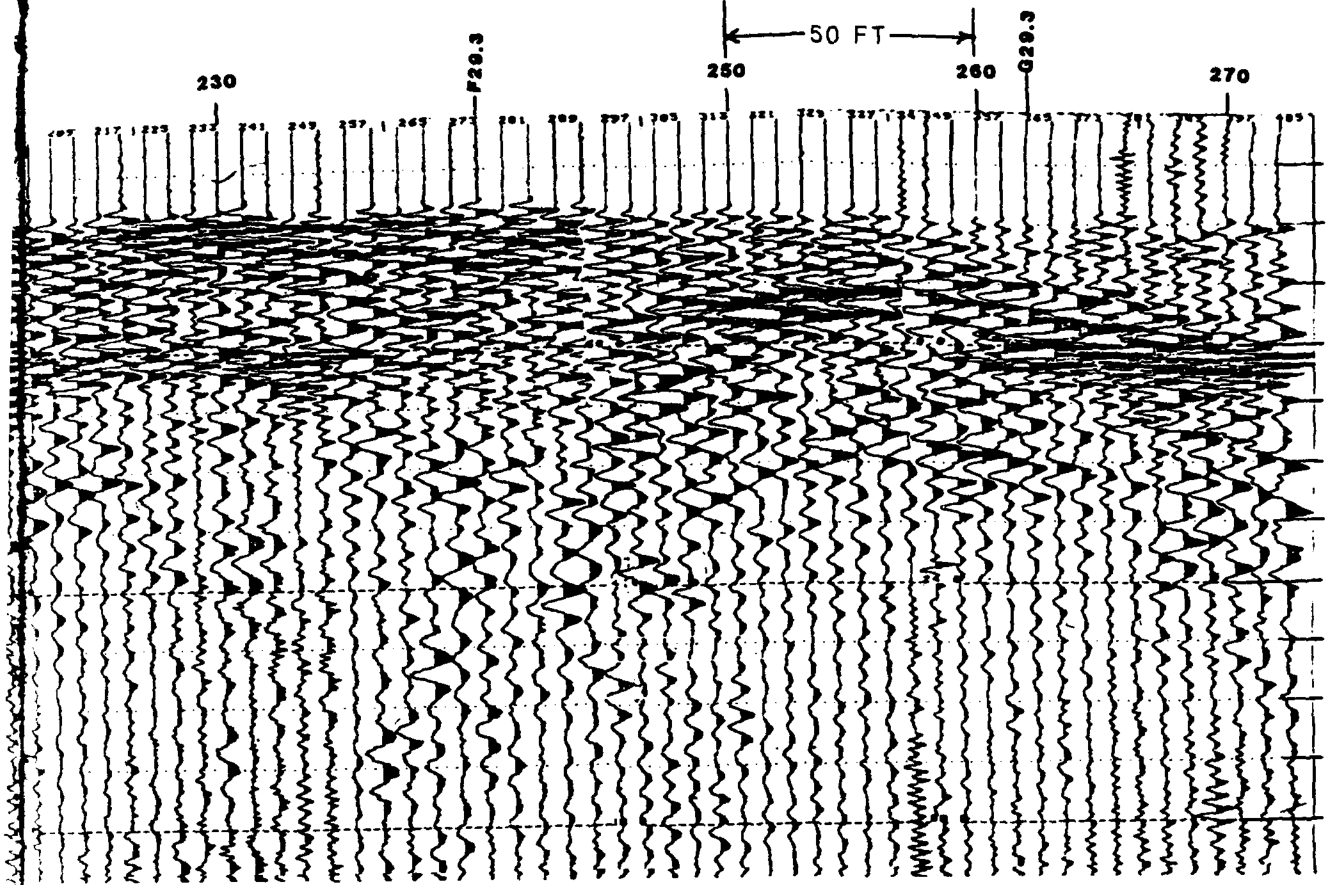
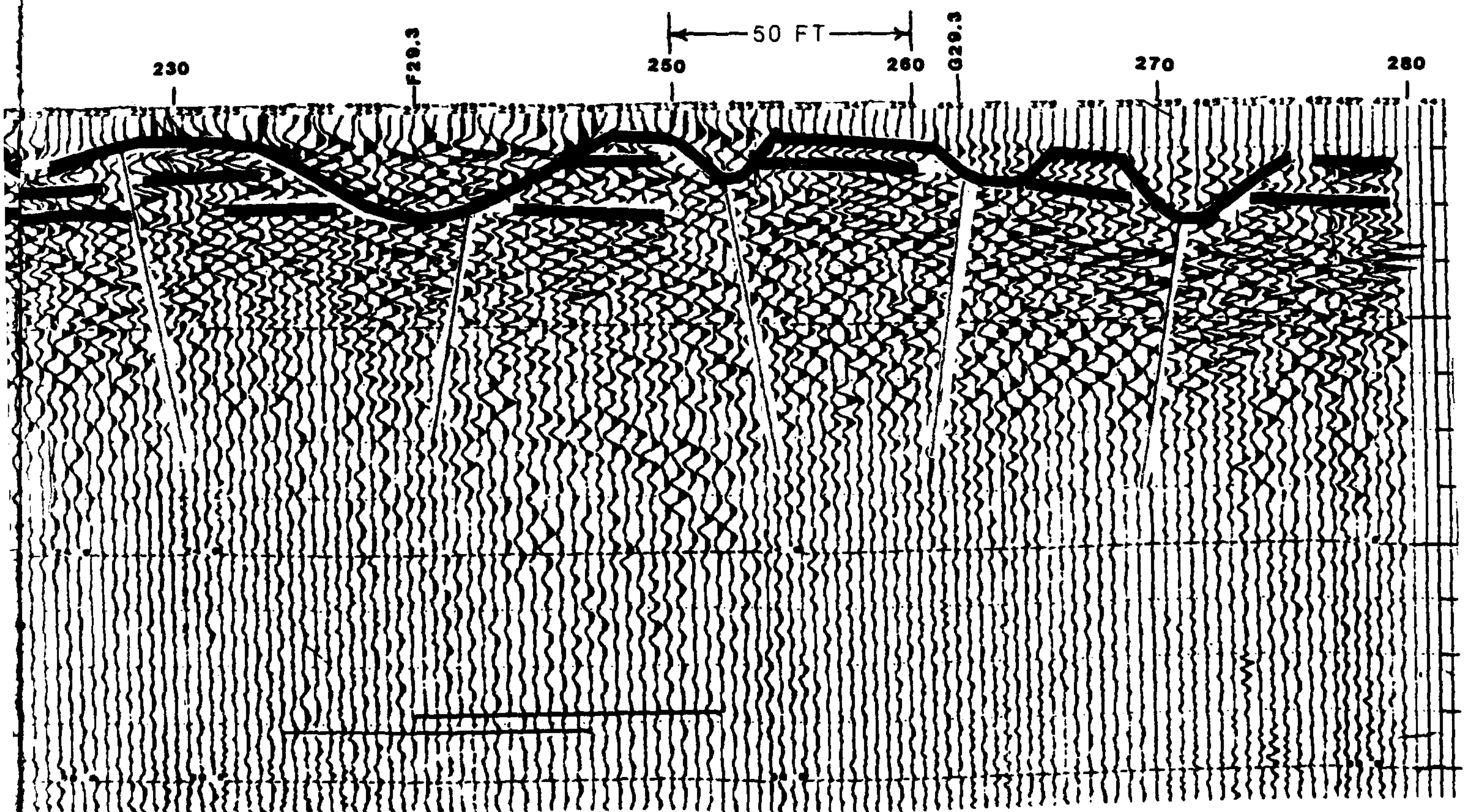


Figure 12. Common offset (
on ES-2420 seismo





Common offset (upper) and CDP stacked sections, produced
ES-2420 seismograph, from Line C-2, Beaver Dam

2

ES-2420 system, and plotting direction could not be controlled. The ES-2420 was used because a large portion of Line C-2 data was destroyed after acquisition and not available for further processing. The key reflections on this section are the bottom of fill/original land surface interface and the top of competent rock. Superimposed on this section are the faults determined from Line C-1.

52. Figure 13 is the result of shallow drilling (US Army Corps of Engineers 1986) in this area which shows striking correlation to Line C-2. The reflection data faithfully reproduce the deep fill section and level competent rock interface near boring E29.5. Borings indicate that the weathered layer is much thicker when the faults reach the surface. These zones are typically where the majority of leakage through the foundation occurs. It is desirable then to locate other faults along the foundation and their corresponding weathered zones near the surface.

53. The very shallow data on Line C-2 does not give a good indication of faults directly, but the data show a good profile of the boundary between the weathered zone and solid rock. Several zones of deep weathering are also seen over fairly narrow lateral limits. Blue lines in Figure 12 indicate stratified rock. The green lines indicate the interface between weathered and solid rock. Deep weathering zones correlate with fault zones. The mechanical fracturing due to faulting has increased the susceptibility of the bedrock to dissolution, cavities/void formation, and enhanced weathering.

54. Seismic reflection therefore has been able to detect shallow zones of deep weathering (to approximately 25 m depth) in the bedrock. When coupled with deep structural data, the weathered zones are seen to be fault controlled. Subsequent drilling for piezometer installation and exploratory boreholes revealed brecciated rock core (gouge) in the interior of the graben in the vicinity of the 'faults' mapped by seismic reflection. No mappable offsets were detected by the drilling interior to the graben, however.

55. Engineering seismographs could have produced equivalent results along this line with a few modification. High pass analog filtering (pre-A/D) on the order of 200 to 300 Hz would be necessary. Data would have to be taken in CDP fashion which would require specialized cabling and a roll-along switch. Finally, software for correcting NMO, CDP sorting, and CDP stack would need to be either purchased or written.

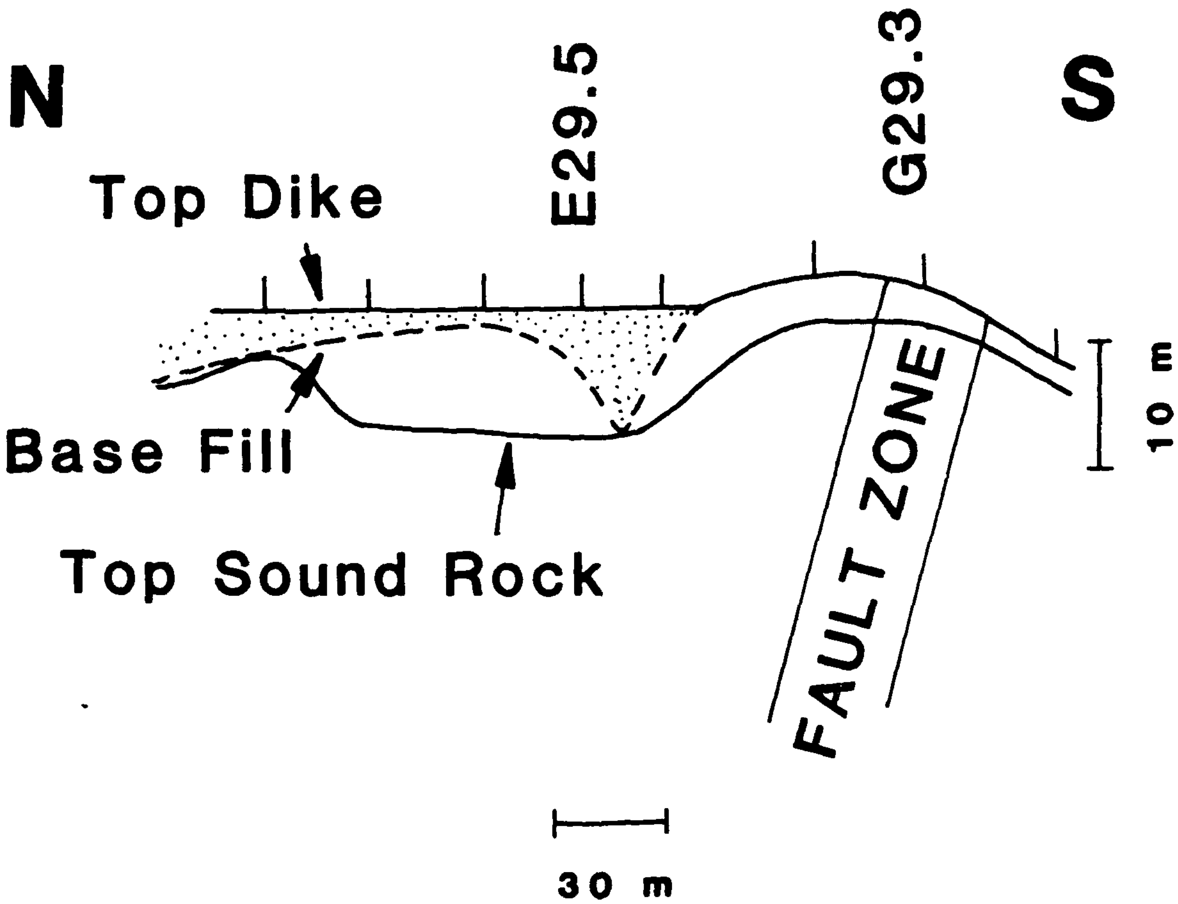


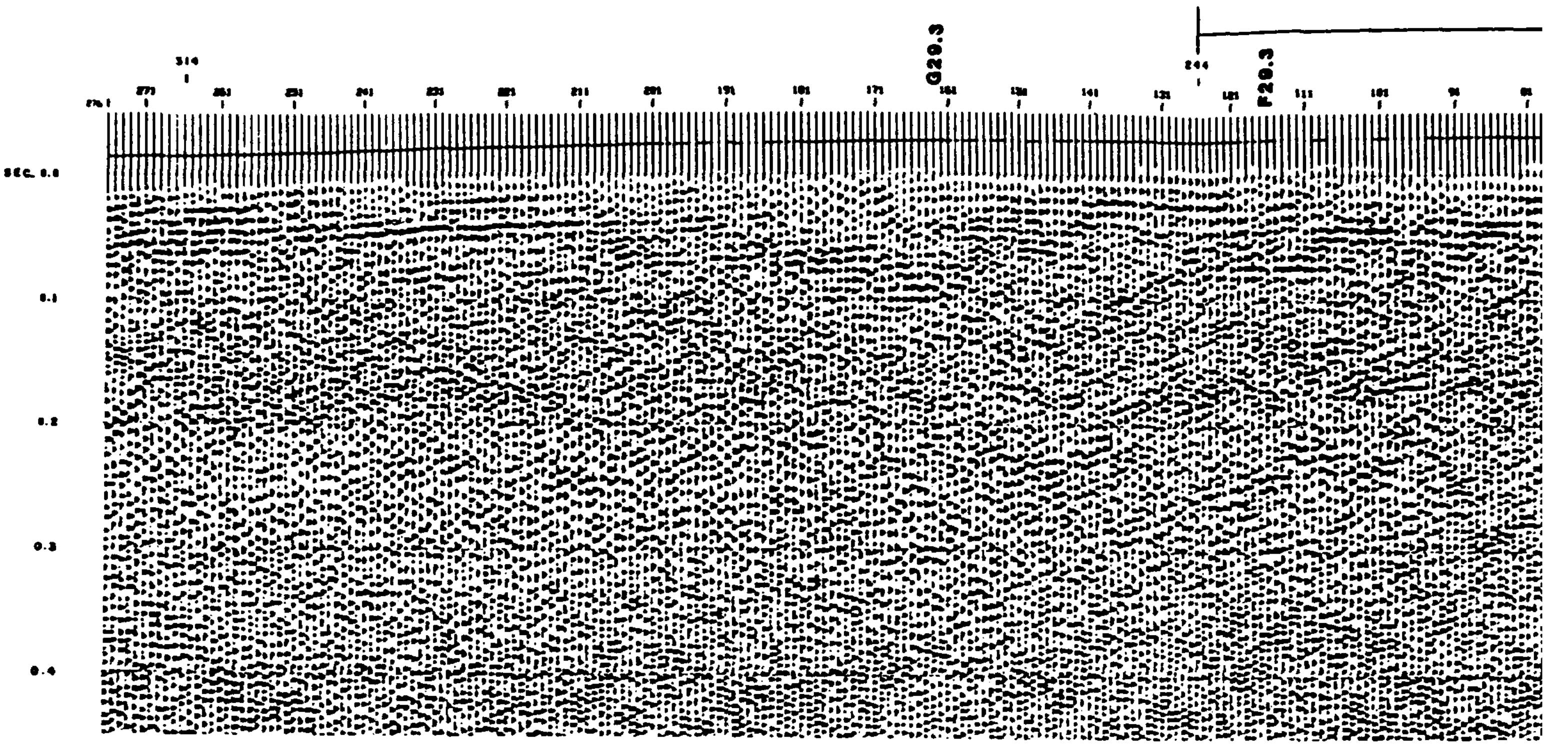
Figure 13. Results of shallow drilling program at Dike No. 1, Beaver Dam, in area of seismic Line C-2

Comparison of Field Methods Used

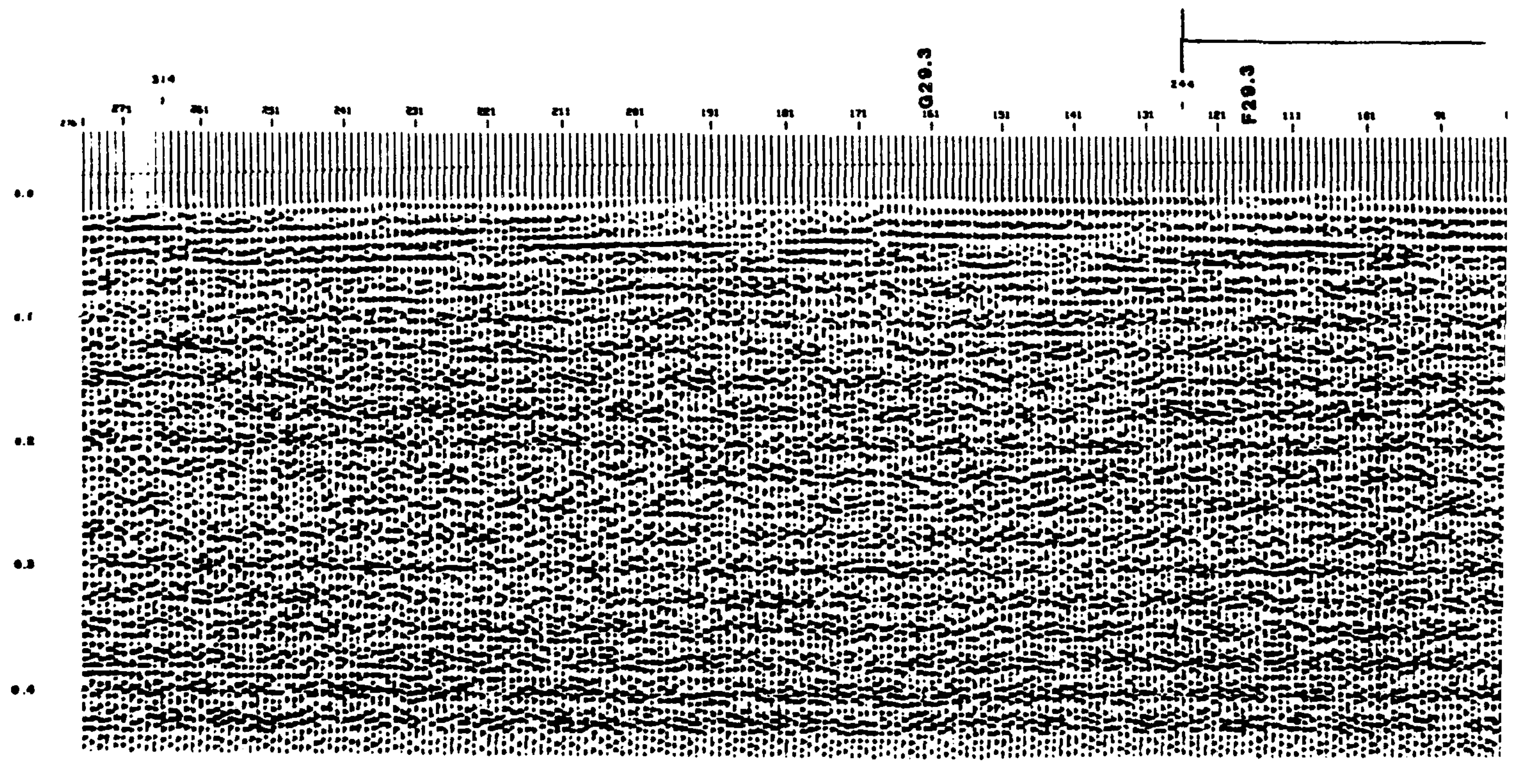
56. One result of this project was a comparison of field acquisition methods for high-resolution seismic. The final stack and Migration on Line C-3 are given in Figure 14 (also, Plates 3 and 4). This can be compared with Line C-1 directly for quality (Figure 11). While some variations in processing were necessary to optimize the results from both field methods, processing was as parallel as possible. Figure 15 shows Flags 181 to 256 on both Lines C-1 and C-3. The most obvious difference between them is energy penetration and signal to noise ratio. Figure 15 is over the southern edge or Dike No. 1 where the most fracturing occurred at the graben's edge. The continuity of events is much better on Line C-1. While neither line allows differentiation of all the individual faults over the zone, at least major sedimentary features and faults can be discerned on Line C-1. On Line C-3 between Flags 214 and 244, little interpretation can be made except to call it a "disturbed zone". On Line C-1 over the same interval, several large structural features can be interpreted. It seems that the extra time and money involved to collect the data by the method used on Line C-1 is worthy for the additional resolution. In addition, Line C-3 is really a better case since velocities picked on Line C-1 were applied on Line C-3. Normally, the processor would not have been able to pick velocities as accurately for Line C-3 if it alone was available for analysis.

57. Therefore, Line C-3 would probably have been adequate to locate major faults in Dike No. 1 area in this sense, rapid and inexpensive seismic methods would have been sufficient. However, in seeing the improvement solely due to extra care and the use of geophone arrays gained on Line C-1, Line C-3 procedure cannot be recommended. For future surveys, easier to manage arrays could be used; also, the sledgehammer would probably be a very good source. Time savings could be realized while retaining high-quality data.

58. Rapid seismic profiling for shallow, foundation description, as per Line C-2, is the preferred method. Using geophone arrays instead of single geophones smears the resolution of shallow reflections by combining the higher frequency components of the signal in an out of phase manner, thus reducing ultimate resolving power. Further, the sledgehammer source was certainly adequate. Care must be taken to minimize airwave energy, reduce groundroll via high pass filtering and high frequency geophones, and predetermine proper



314
244
G20.3
F20.3
SEC. 0.0
0.1
0.2
0.3
0.4



314
244
G20.3
F20.3
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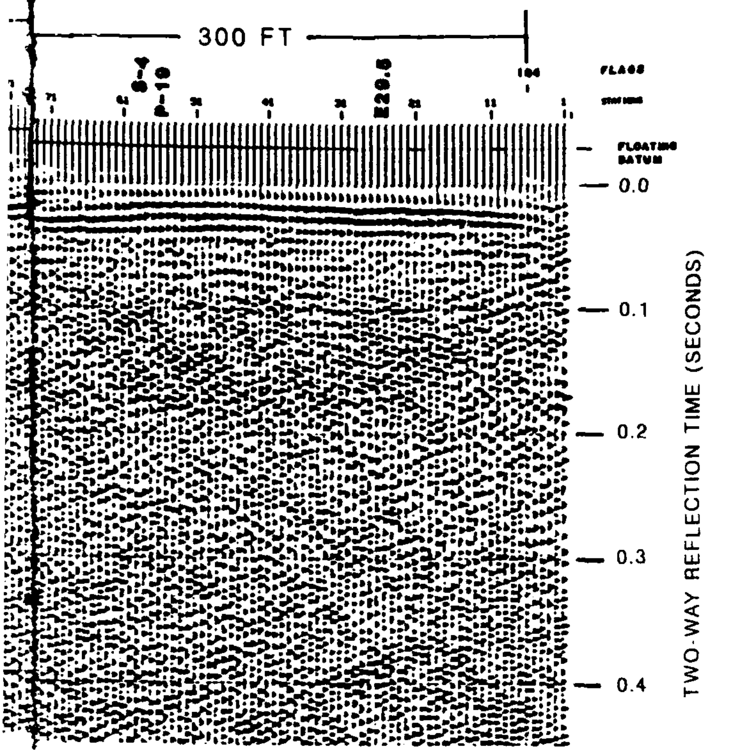
0.4

Figure 14.



COMPUTING

COMPUTED AT CGG DATA PROCESSING CENTER
1616 CHAMPA ST., DENVER COLORADO
DATUM PLANE: 1000 FT. CORRECTIONAL VELOCITY: 2000 FT./SEC.

GEOMASTER PROCESSING SEQUENCE

01-DEMULTIPLEX
02-GAIN COMPENSATION FOR TRANSMISSION LOSS AND SPHERICAL DIVERGENCE
03-CDP SORT
04-GEOPHONE EDITS
05-SHOT AND TRACE EDITS
07-STATICS TO FLAT DATUM
08-SPIKING DECONVOLUTION
OPERATOR LENGTH 40 MSEC.
WINDOW FROM 62.5 TO 250 MSEC.
09-AUTOMATIC RESIDUAL STATICS
10-VELOCITY ANALYSIS
11-NMO CORRECTION
12-MUTES
13-AUTOMATIC RESIDUAL STATICS
14-CDP STACK
15-BAND PASS FILTER
72/80-180/220 HZ
16-DYNAMIC TRACE EQUALIZATION
17-STATICS TO FLOATING DATUM
18-FILM DISPLAY

DISPLAY PARAMETERS

HORIZONTAL SCALE: 12 TRACES PER INCH
VERTICAL SCALE: 14 INCHES PER SECOND
POLARITY: FIELD POLARITY

QUALITY CONTROL

DATE NOVEMBER 1986 CGG ACCT. NO.: 4223101
PROCESSED BY: TANYA MUELLER CHECKED BY: DR. T.L. DOBECKI
MONROE B. SAVAGE

SCALE

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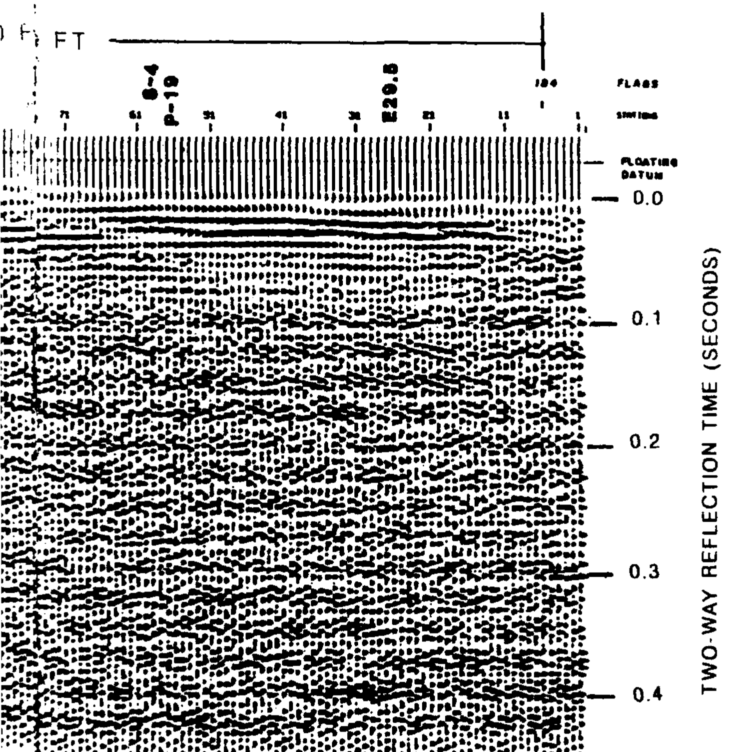

COMPUTING

COMPUTED AT CGG DATA PROCESSING CENTER
1616 CHAMPA ST., DENVER COLORADO
DATUM PLANE: 1000 FT. CORRECTIONAL VELOCITY: 2000 FT./SEC.

GEOMASTER PROCESSING SEQUENCE

01-DEMULTIPLEX
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OPERATOR LENGTH 40 MSEC.
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11-NMO CORRECTION
12-MUTES
13-AUTOMATIC RESIDUAL STATICS
14-CDP STACK
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72/80-180/220 HZ
16-DYNAMIC TRACE EQUALIZATION
17-STATICS TO FLOATING DATUM
18-WAVE EQUATION MIGRATION
19-BAND PASS FILTER
20-DYNAMIC TRACE EQUALIZATION
21-FILM DISPLAY

DISPLAY PARAMETERS

HORIZONTAL SCALE: 12 TRACES PER INCH
VERTICAL SCALE: 14 INCHES PER SECOND
POLARITY: FIELD POLARITY

QUALITY CONTROL

DATE NOVEMBER 1986 CGG ACCT. NO.: 4223101
PROCESSED BY: TANYA MUELLER CHECKED BY: DR. T.L. DOBECKI
MONROE B. SAVAGE

SCALE

sections (upper is final stack; lower is migrated stack) from Line C-3, Beaver Dam

2

FLAGS

STATIONS

FLOATING DATUM

0.0

0.1

0.2

0.3

0.4

TWO-WAY REFLECTION TIME (SECONDS)

COMPUTING

COMPUTED AT CGG DATA PROCESSING CENTER
1616 CHAMPA ST., DENVER COLORADO
DATUM PLANE: 1000 FT. CORRECTIONAL VELOCITY: 2000 FT./SEC.

GEOMASTER PROCESSING SEQUENCE

01-DEMULTIPLEX
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OPERATOR LENGTH 40 MSEC.
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12-MUTES
13-AUTOMATIC RESIDUAL STATICS
14-CDP STACK
15-BAND PASS FILTER
72/80-180/280 HZ
16-DYNAMIC TRACE EQUALIZATION
17-STATICS TO FLOATING DATUM
18-FILM DISPLAY

DISPLAY PARAMETERS

HORIZONTAL SCALE: 12 TRACES PER INCH
VERTICAL SCALE: 14 INCHES PER SECOND
POLARITY: FIELD POLARITY

QUALITY CONTROL

DATE NOVEMBER 1986 CGG ACCT. NO.: 4223101
PROCESSED BY: TAMMA MUELLER CHECKED BY: DR. T.L. DOBECKI
MONROE B. SAVAGE

SCALE
30 TR. = 1/40 MILE

WATERWAYS EXPERIMENT STATION

COMPANY

BEAVER DAM ARKANSAS

AREA

LINE C-3

LINE

288 1

STATIONS

SOUTH NORTH

FINAL EQUALIZED STACK

FIELD RECORDING

RECORDED BY: CSM CREW
FIELD SYSTEM: ES-2420
ENERGY SOURCE: HAMMER
NO. OF HITS/HOLE: 9
24 SINGLE GEOPHONES
GEOPHONE TYPE: OSS
GEOPHONE SPACING: 5 FT.
RECORDING FILTERS: LC: 25 HZ
HC: 780 HZ
NOTCH 60 HZ

DATE: AUGUST 1986
FORMAT: SEGD
SAMPLE INTERVAL: .25 MSEC
RECORD LENGTH .5 SEC.
FOLD 6
GEOPHONE FREQUENCY: 100 HZ
SHOTPOINT INTERVAL: 10 FT.
SLOPE: 18 DB/OCT
SLOPE: 18 DB/OCT

FLAGS

STATIONS

FLOATING DATUM

0.0

0.1

0.2

0.3

0.4

TWO-WAY REFLECTION TIME (SECONDS)

COMPUTING

COMPUTED AT CGG DATA PROCESSING CENTER
1616 CHAMPA ST., DENVER COLORADO
DATUM PLANE: 1000 FT. CORRECTIONAL VELOCITY: 2000 FT./SEC.

GEOMASTER PROCESSING SEQUENCE

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POLARITY: FIELD POLARITY

QUALITY CONTROL

DATE NOVEMBER 1986 CGG ACCT. NO.: 4223101
PROCESSED BY: TAMMA MUELLER CHECKED BY: DR. T.L. DOBECKI
MONROE B. SAVAGE

SCALE
30 TR. = 1/40 MILE

WATERWAYS EXPERIMENT STATION

COMPANY

BEAVER DAM ARKANSAS

AREA

LINE C-3

LINE

288 1

STATIONS

SOUTH NORTH

WAVE EQUATION MIGRATION

FIELD RECORDING

RECORDED BY: CSM CREW
FIELD SYSTEM: ES-2420
ENERGY SOURCE: HAMMER
NO. OF HITS/HOLE: 9
24 SINGLE GEOPHONES
GEOPHONE TYPE: OSS
GEOPHONE SPACING: 5 FT.
RECORDING FILTERS: LC: 25 HZ
HC: 780 HZ
NOTCH 60 HZ

DATE: AUGUST 1986
FORMAT: SEGD
SAMPLE INTERVAL: .25 MSEC
RECORD LENGTH .5 SEC.
FOLD 6
GEOPHONE FREQUENCY: 100 HZ.
SHOTPOINT INTERVAL: 10 FT.
SLOPE: 18 DB/OCT
SLOPE: 18 DB/OCT

s migrated stack)

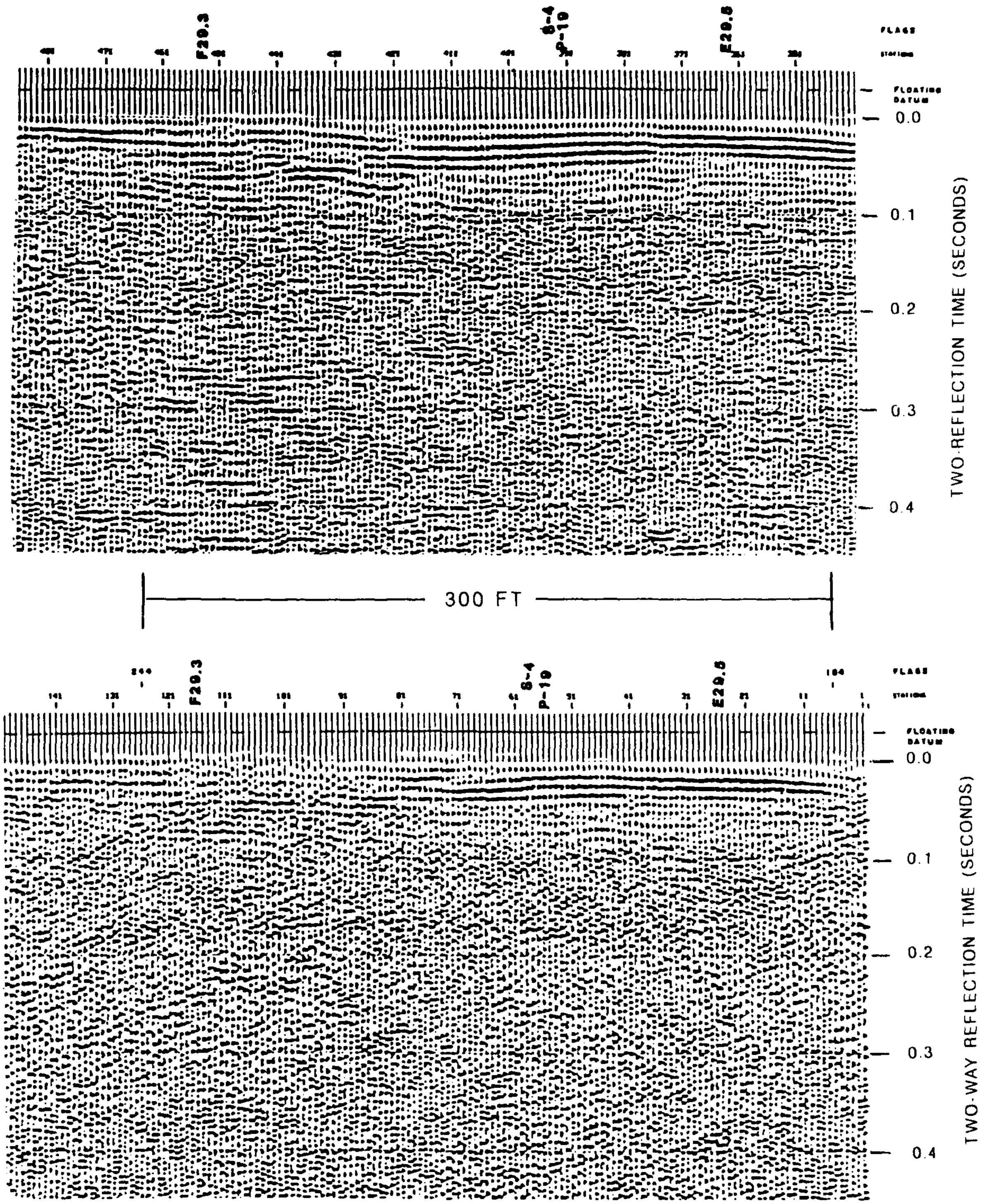

Figure 15. Direct comparison for identical processing of seismic section from Line C-1 (top) and Line C-3 (bottom) for the same subsurface coverage

shot-geophone spread geometries. Shooting in CDP fashion dramatically aided interpretation and resolution on smaller anomalous features. This would however require some specialized equipment (CDP cables and roll-along switch) and some minimal processing capability for CDP sort, NMO, and stack. These are readily available from equipment/cable manufacturers and can be purchased/written for IBM-type microcomputers. Such measurements can therefore be easily made with even a 12-channel engineering seismograph with minor modifications.

PART VII: SUMMARY AND CONCLUSIONS

59. Seismic reflection data taken at Dike No. 1, Beaver Dam, AR, have shown that the dike area has been affected greatly by faulting whose influence extends all the way up to the bedrock surface. More faulting than suspected by early drilling programs has been detected. Each fault is also the locus of deep weathering of the dike foundation rock. The soluble vuggy Boone formation not only has been dropped down to form the dike foundation which causes seepage, but also has been fractured by faulting to increase the dissolution which adds to the problem.

60. Common depth point data acquisition techniques were generally proven superior to the simple common offset methods of Hunter et al. (1984). Geophone arrays were preferred for deep structural reflection data, and single geophones with high pass filtering were preferred for shallow foundation investigation. The high-resolution seismic reflection surveys were successful in delineating a weathered, irregular top of rock beneath Dike 1 at depths of 20 to 80 ft (6 to 24 m). The deeper structure (∿200 ft) of the graben was also delineated. Also, evidence of previously unsuspected faults in the interior of the downfaulted block was observed in the seismic sections.

61. For the deeper data, advanced data processing methods proved superior to using very simple filtering and stacking techniques. More simple techniques however were actually preferred for the very shallow data. In either case, deep or shallow, some processing capability coupled with adding CDP acquisition capability will be required for the use of engineering seismographs to acquire similar reflection data on future projects.

62. High-resolution seismic surveying is a rapidly advancing methodology in all areas: engineering seismographs, field procedures, seismic sources, data processing procedures, and office and field-portable microcomputers. Even during the time since the fieldwork at Beaver Dam was performed, significant advances have been made. These advances have resulted not only in lower cost but also in improved data product. A high-resolution seismic reflection survey, covering about 1,000 ft (305 m) with 12-fold CDP, 4 ft (1.2 m) geophone intervals, and 4 ft (1.2 m) shot points, would cost about $12,000. This estimated cost is for a site within a day's mobilization distance from the contractor and for a simple site and objective, i.e., easy site access, no elevation surveying required (site either flat or survey

data supplied to contractor), and a well-defined mapping objective (e.g., irregular top of rock at 30 to 50 ft (9 to 15 m) depth and shallower anomalies). The cost of the work conducted at Beaver Dam was approximately $35,000 and included multiple mapping objectives as well as 'research' objectives (seismic source evaluation, geophone array optimization, data processing requirements assessment).

REFERENCES

Butler, D. K., and Curro, J. R. 1981. "Crosshole Seismic Testing Procedures and Pitfalls," Geophysics, Vol 46, pp 23-29.

Dobecki, T. L., and Romig, P. R. 1985. "Geotechnical and Ground-Water Geophysics," Geophysics, Vol 50, pp 2621-2636.

Hunter, J. A., Pullen, S. E., Burns, R. A., Gagne, R. M., and Good, R. L. 1984. "Shallow Seismic Reflection Mapping of the Overburden-Bedrock Interface with the Engineering Seismograph-Some Simple Techniques," Geophysics, Vol 49, pp 1381-1385.

Keller, G. V. 1974. "Engineering Applications of Electrical Geophysical Methods: In Subsurface Exploration for Underground and Heavy Construction," American Society of Civil Engineers, NY.

Llopis, J. L., and Butler, D. K. 1988. "Geophysical Investigation in Support of Beaver Dam Comprehensive Seepage Investigation," Technical Report GL-88-6, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

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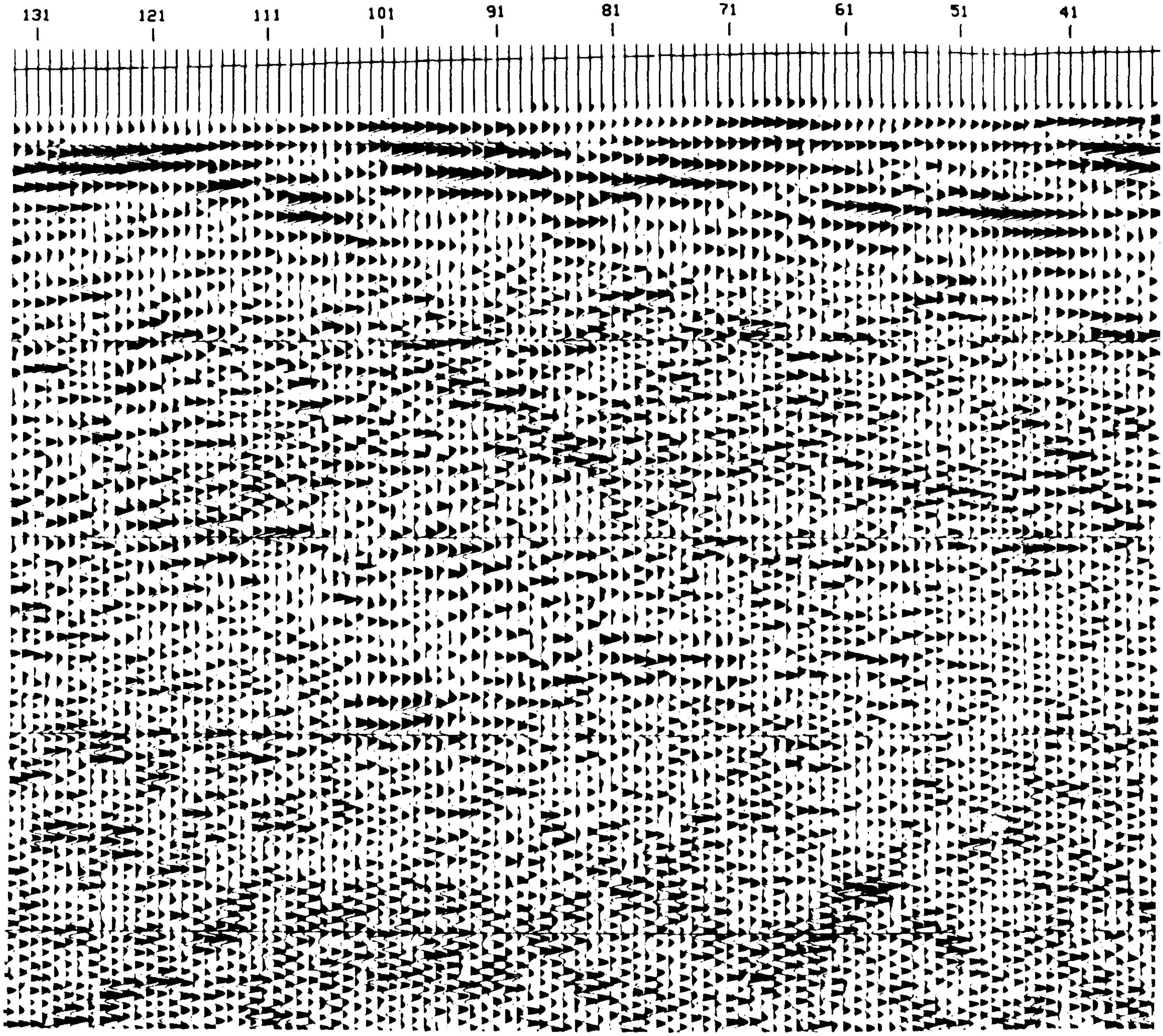
US Army Corps of Engineers. 1986. "Beaver Dam, White River Arkansas, Seepage Investigations and Remedial Plan to Control Major Seepage at Dike No. I: Little Rock District," Little Rock, AR.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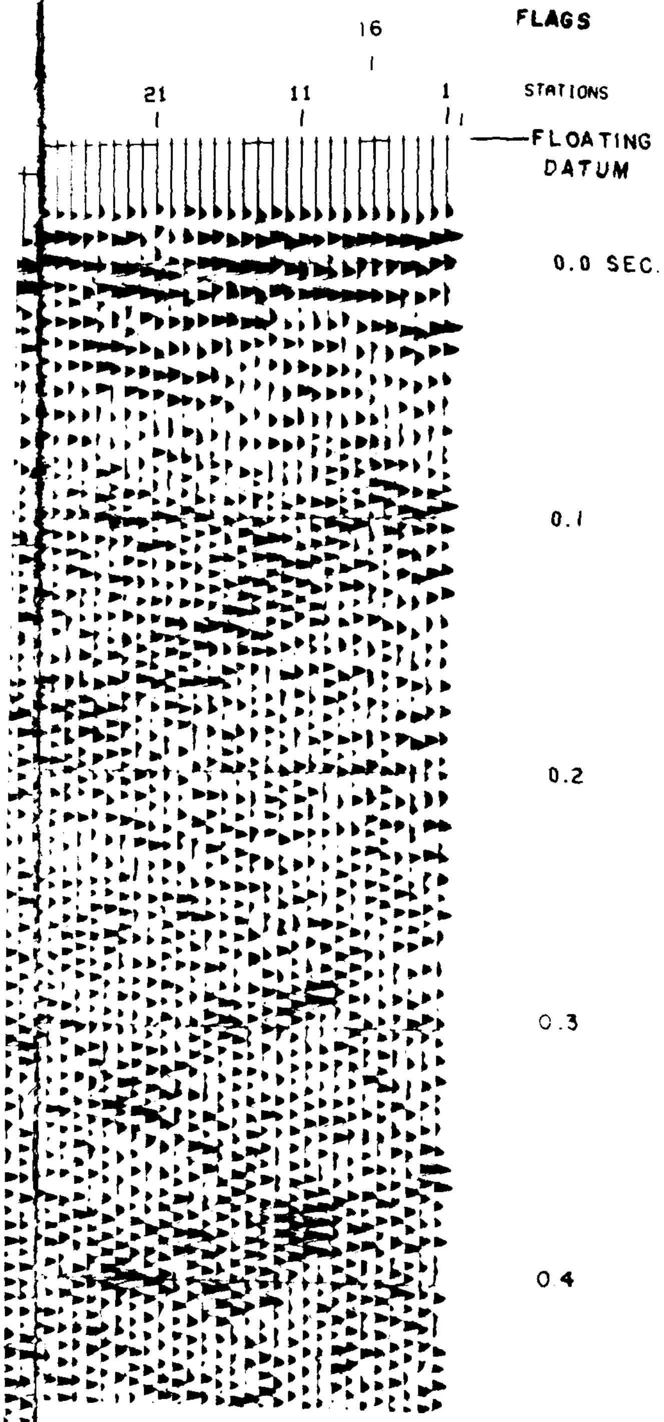

COMPUTING

COMPUTED AT CGG DATA PROCESSING CENTER
1616 CHAMPA ST., DENVER COLORADO
DATUM PLANE: 1080 FT. CORRECTIONAL VELOCITY: 2800 FT./SEC.

GEOMASTER PROCESSING SEQUENCE

01-DEMULTIPLEX
02-GAIN COMPENSATION FOR TRANSMISSION LOSS
AND SPHERICAL DIVERGENCE
03-CDP SORT
04-GEOPHONE EDITS
05-SHOT AND TRACE EDITS
07-STATICS TO FLAT DATUM
08-SPIKING DECONVOLUTION
OPERATOR LENGTH 40 MSEC.
WINDOW FROM 62.5 TO 250 MSEC.
09-AUTOMATIC RESIDUAL STATICS
10-VELOCITY ANALYSIS
11-NMO CORRECTION
12-MUTES
13-AUTOMATIC RESIDUAL STATICS
14-CDP STACK
15-TIME VARIENT BAND PASS FILTER
72/88-240/280 HZ. T0-T100 MSEC.
72/88-180/220 HZ. T150-T500 MSEC.
16-DYNAMIC TRACE EQUALIZATION
17-STATICS TO FLOATING DATUM
18-FILM DISPLAY

DISPLAY PARAMETERS

HORIZONTAL SCALE: 12 TRACES PER INCH
VERTICAL SCALE: 14 INCHES PER SECOND
POLARITY: FIELD POLARITY

QUALITY CONTROL

DATE NOVEMBER 1986
CGG ACCT. NO.: 4223101
PROCESSED BY: TANYA MUELLER
CHECKED BY: DR. T.L. DOBECKI
MONROE B. SAVAGE

SCALE

33 TR. = 1/64 MILE

PLATE 1

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POLARITY

Y CONTROL
CGG ACCT. NO.: 4223101
CHECKED BY: DR. T.L. DOBECKI
MONROE B. SAVAGE

CALE

= 1/64 MILE

WATERWAYS EXPERIMENT STATION
COMPANY

BEAVER DAM ARKANSAS
AREA

LINE C-1
LINE

644 1
STATIONS

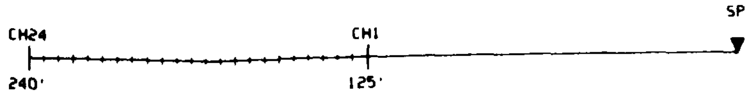
SOUTH NORTH

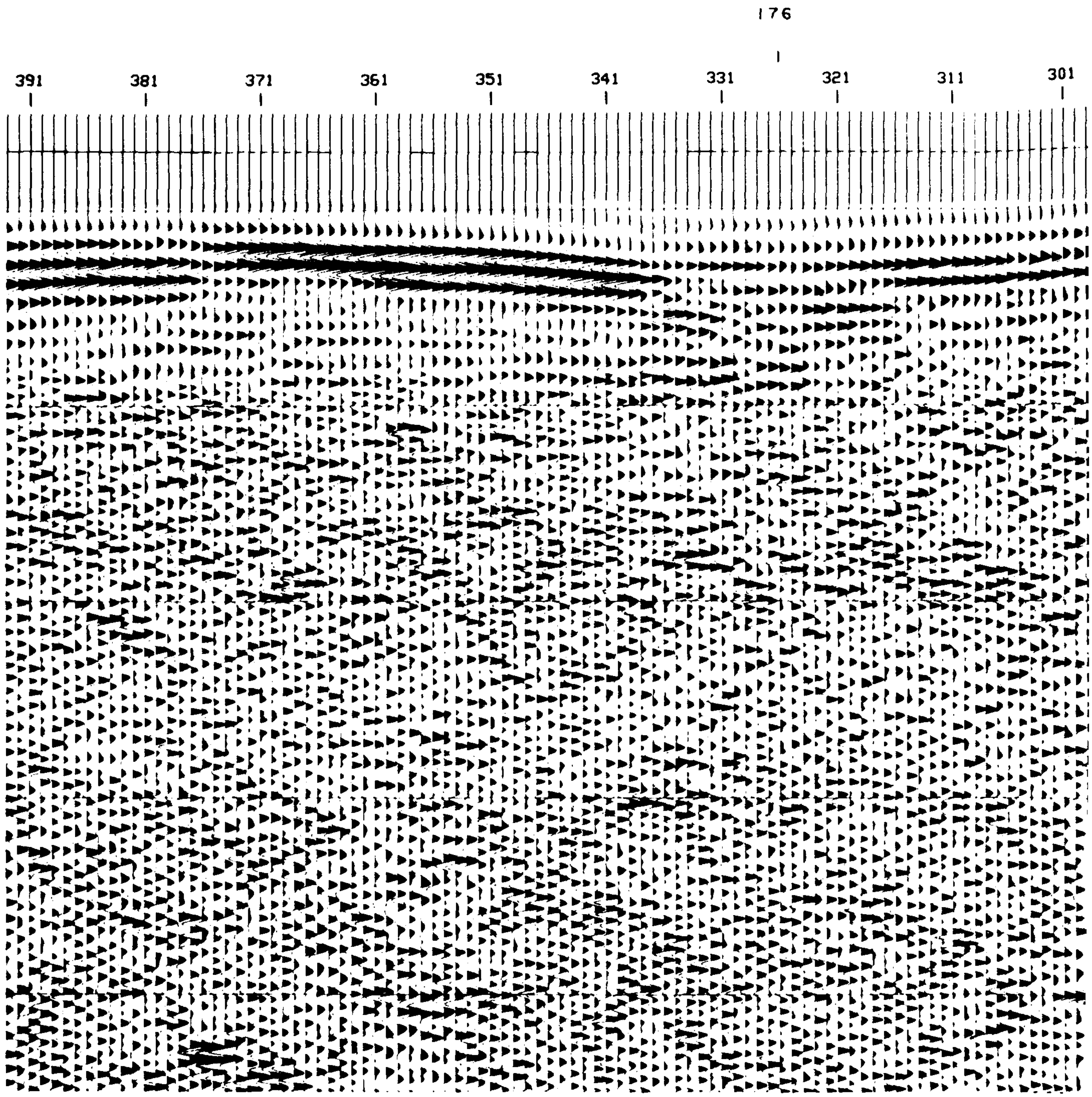
FINAL EQUALIZED STACK

FIELD RECORDING

RECORDED BY: CSM CREW
FIELD SYSTEM: ES-2420
ENERGY SOURCE: BUFFALO GUN
NO. OF SHOTS/HOLE: 3
GROUP INTERVAL: 5 FT.
NUMBER OF GROUPS: 24
GEOPHONE TYPE: GSC-20D
GEOPHONE ARRAY: 25 FT.
RECORDING FILTERS: LC: 25 HZ
HC: 720 HZ
NOTCH: 60 HZ

DATE: AUGUST 1986
FORMAT: SEGD
SAMPLE INTERVAL: .25 MSEC.
RECORD LENGTH: .5 SEC.
FOLD: 6
SHOTPOINT INTERVAL: 10 FT.
GEOPHONE FREQUENCY: 8 HZ.
GEOPHONE SPACING: 5 FT.
SLOPE: 18 DB/OCT
SLOPE: 18 DB/OCT

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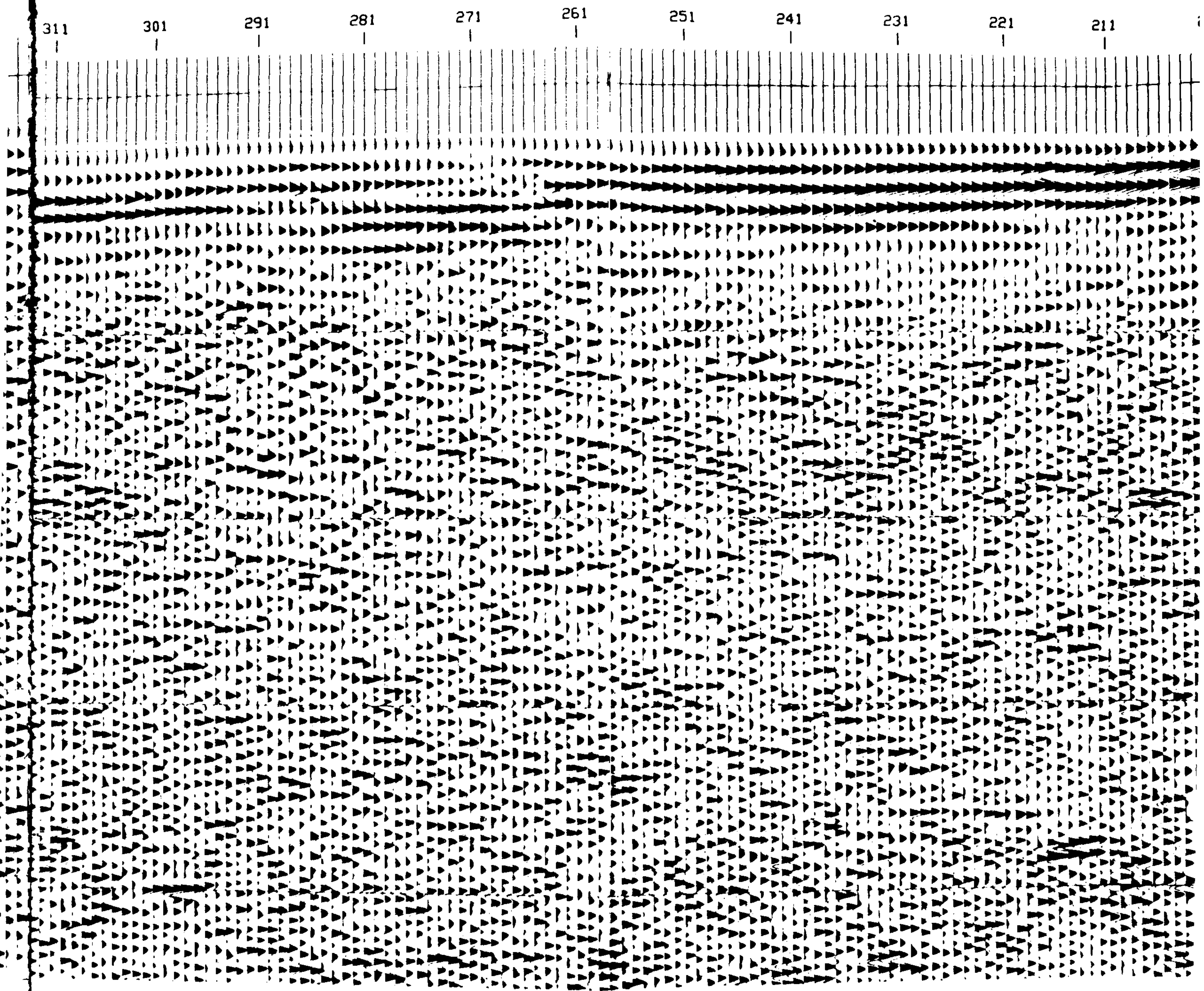

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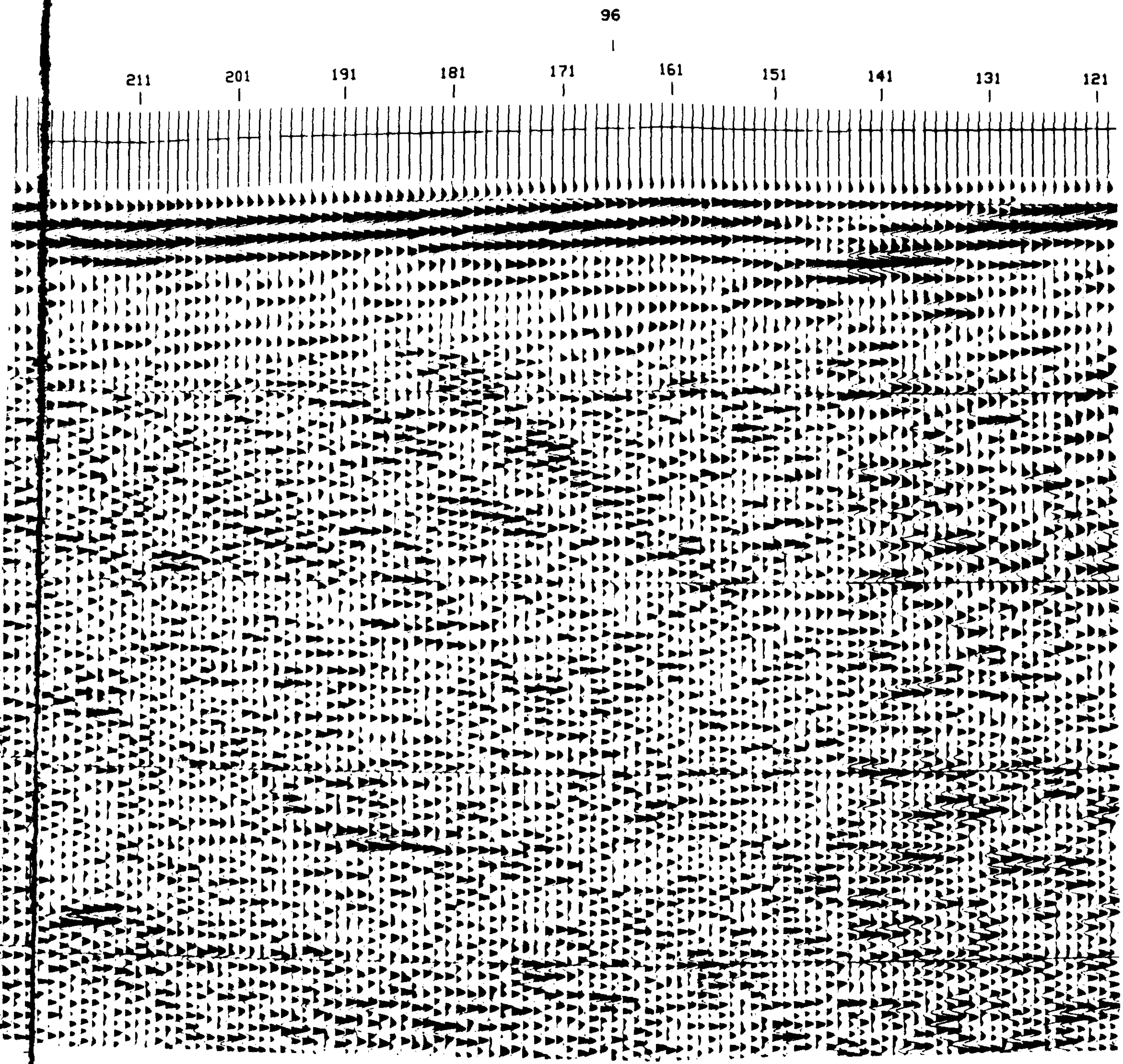

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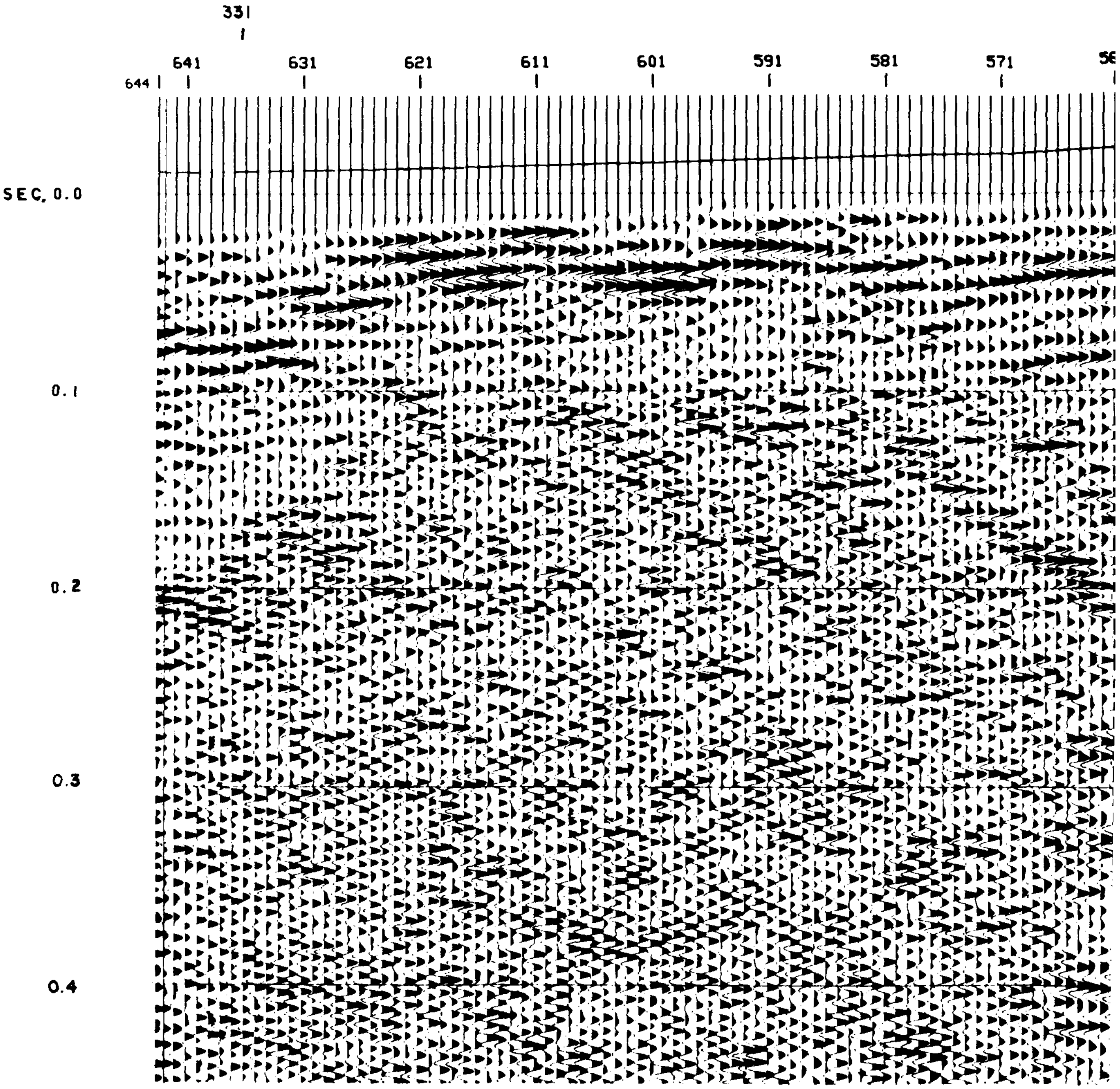
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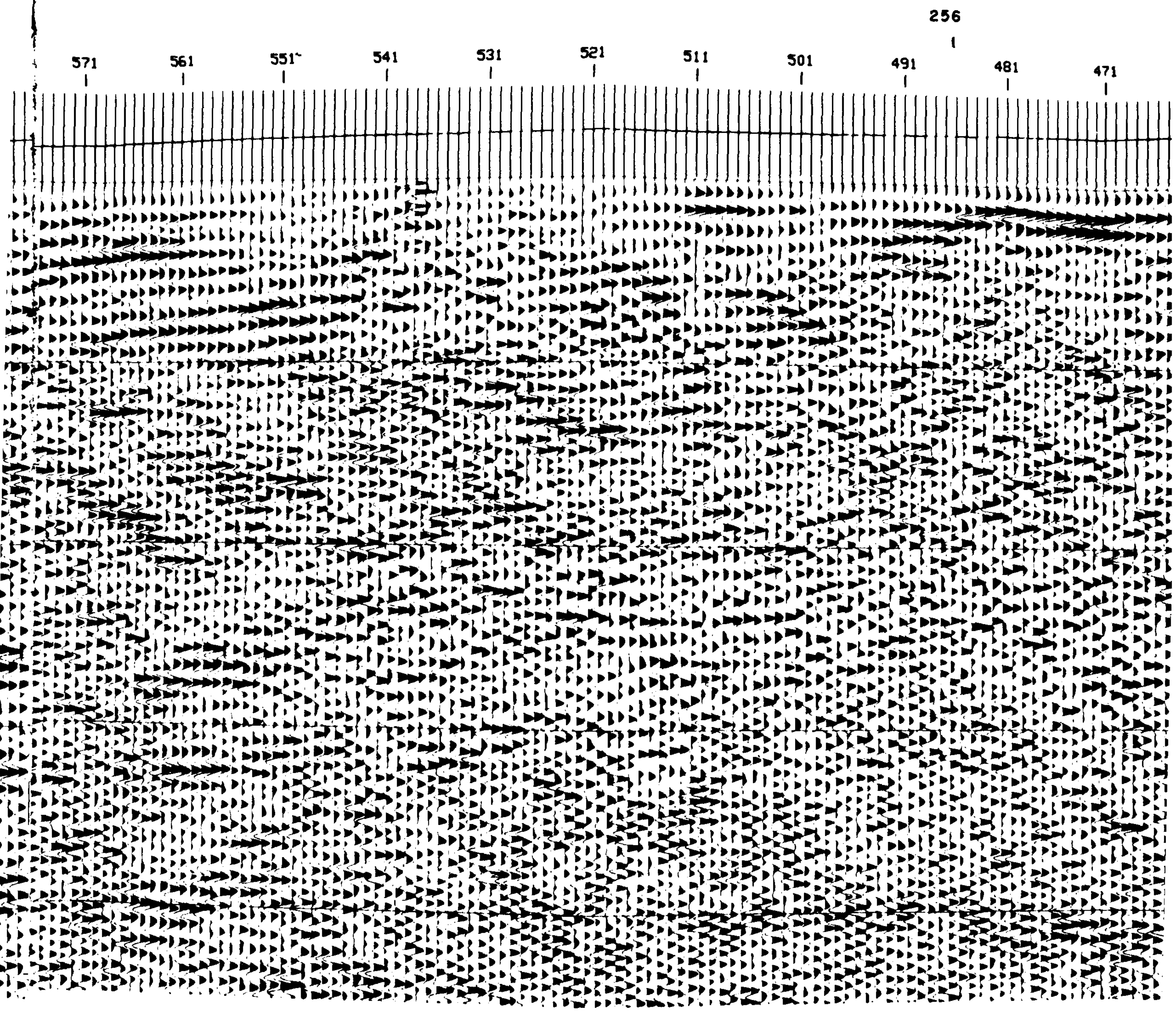
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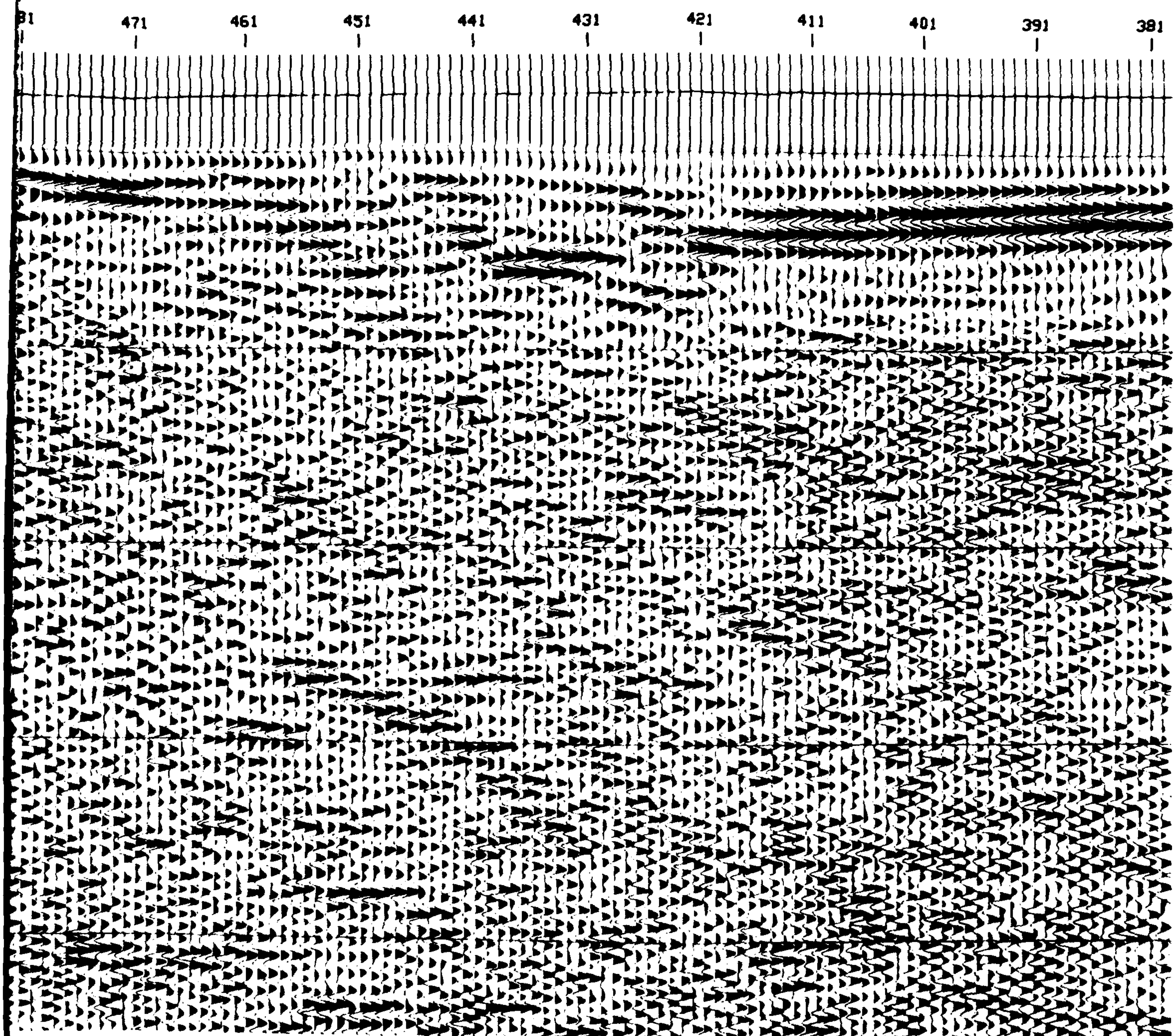

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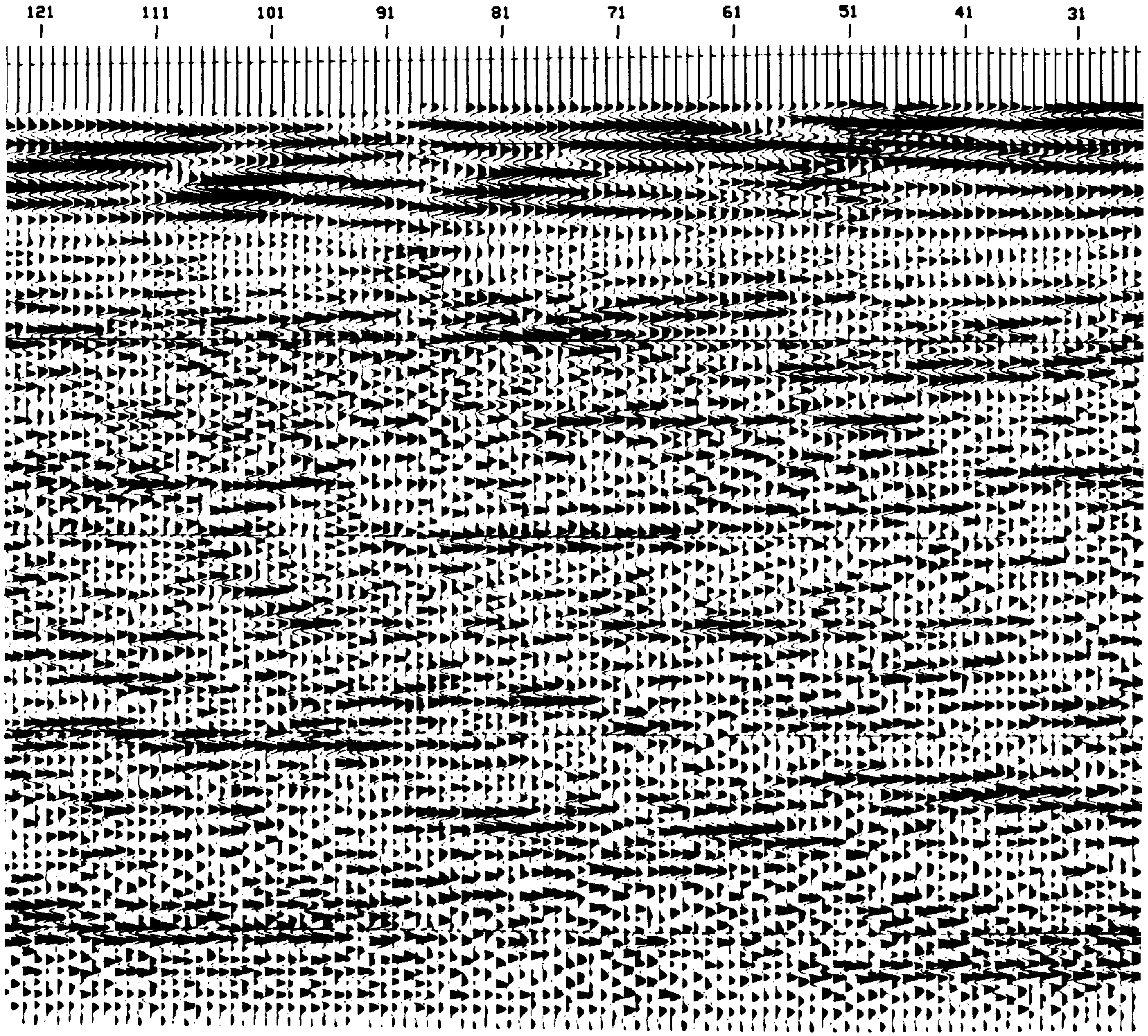
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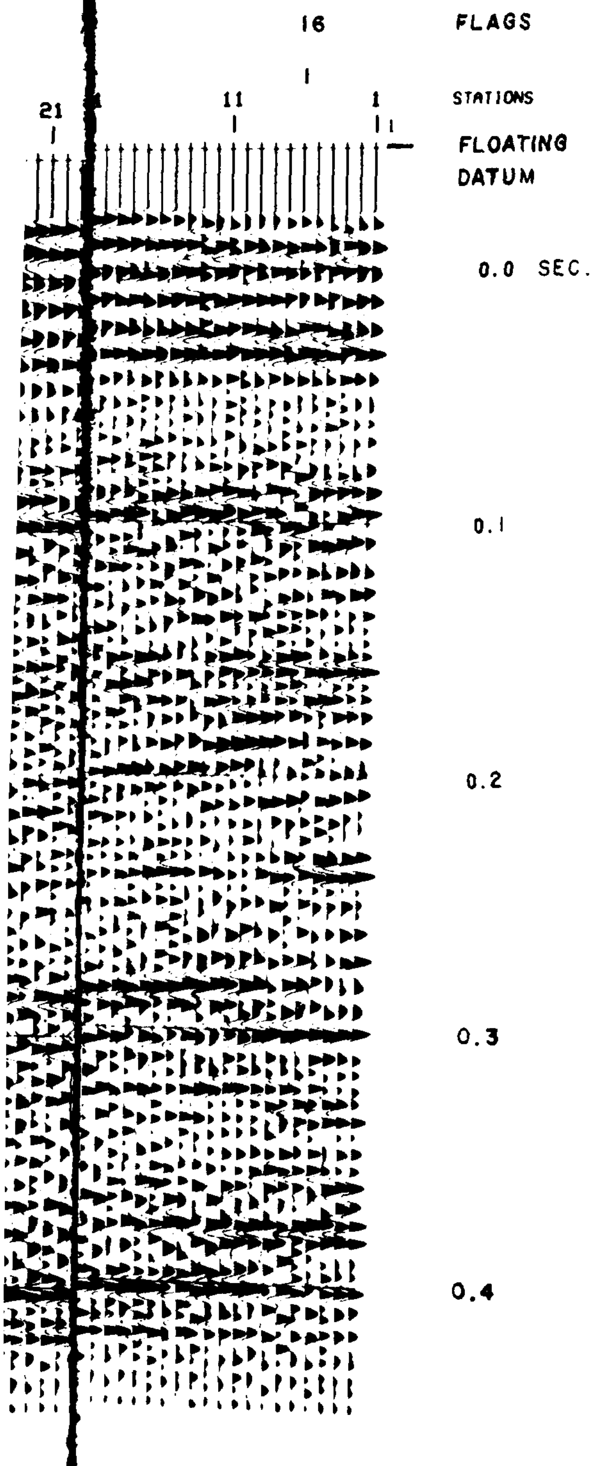

COMPUTING

COMPUTED AT CGG DATA PROCESSING CENTER
1616 CHAMPA ST., DENVER COLORADO
DATUM PLANE: 1080 FT. CORRECTIONAL VELOCITY: 2800 FT./SEC.

GEOMASTER PROCESSING SEQUENCE

01-DEMULTIPLEX
02-GAIN COMPENSATION FOR TRANSMISSION LOSS
AND SPHERICAL DIVERGENCE
03-CDP SORT
04-GEOPHONE EDITS
05-SHOT AND TRACE EDITS
07-STATICS TO FLAT DATUM
08-SPIKING DECONVOLUTION
OPERATOR LENGTH 40 MSEC.
WINDOW FROM 62.5 TO 250 MSEC.
09-AUTOMATIC RESIDUAL STATICS
10-VELOCITY ANALYSIS
11-NMO CORRECTION
12-MUTES
13-AUTOMATIC RESIDUAL STATICS
14-CDP STACK
15-TIME VARIENT BAND PASS FILTER
72/88-240/280 HZ. T0-T100 MSEC.
72/88-180/220 HZ. T150-T500 MSEC.
16-DYNAMIC TRACE EQUALIZATION
17-STATICS TO FLOATING DATUM
18-WAVE EQUATION MIGRATION
19-BAND PASS FILTER
20-DYNAMIC TRACE EQUALIZATION
21-FILM DISPLAY

DISPLAY PARAMETERS

HORIZONTAL SCALE: 12 TRACES PER INCH
VERTICAL SCALE: 14 INCHES PER SECOND
POLARITY: FIELD POLARITY

QUALITY CONTROL

DATE NOVEMBER 1986 | CGG ACCT. NO.: 4223101
PROCESSED BY: TANYA MUELLER | CHECKED BY: DR. T.L. DOBECKI
MONROE B. SAVAGE

SCALE
33 TR. = 1/64 MILE

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GG ACCT. NO.: 4223101
HECKED BY: DR. T.L. DOBECKI
MONROE B. SAVAGE

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1/64 MILE

PLATE 2

WATERWAYS EXPERIMENT STATION
COMPANY

BEAVER DAM ARKANSAS
AREA

LINE C-1
LINE

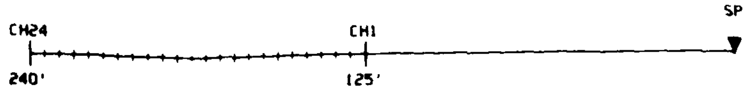
644 1
STATIONS

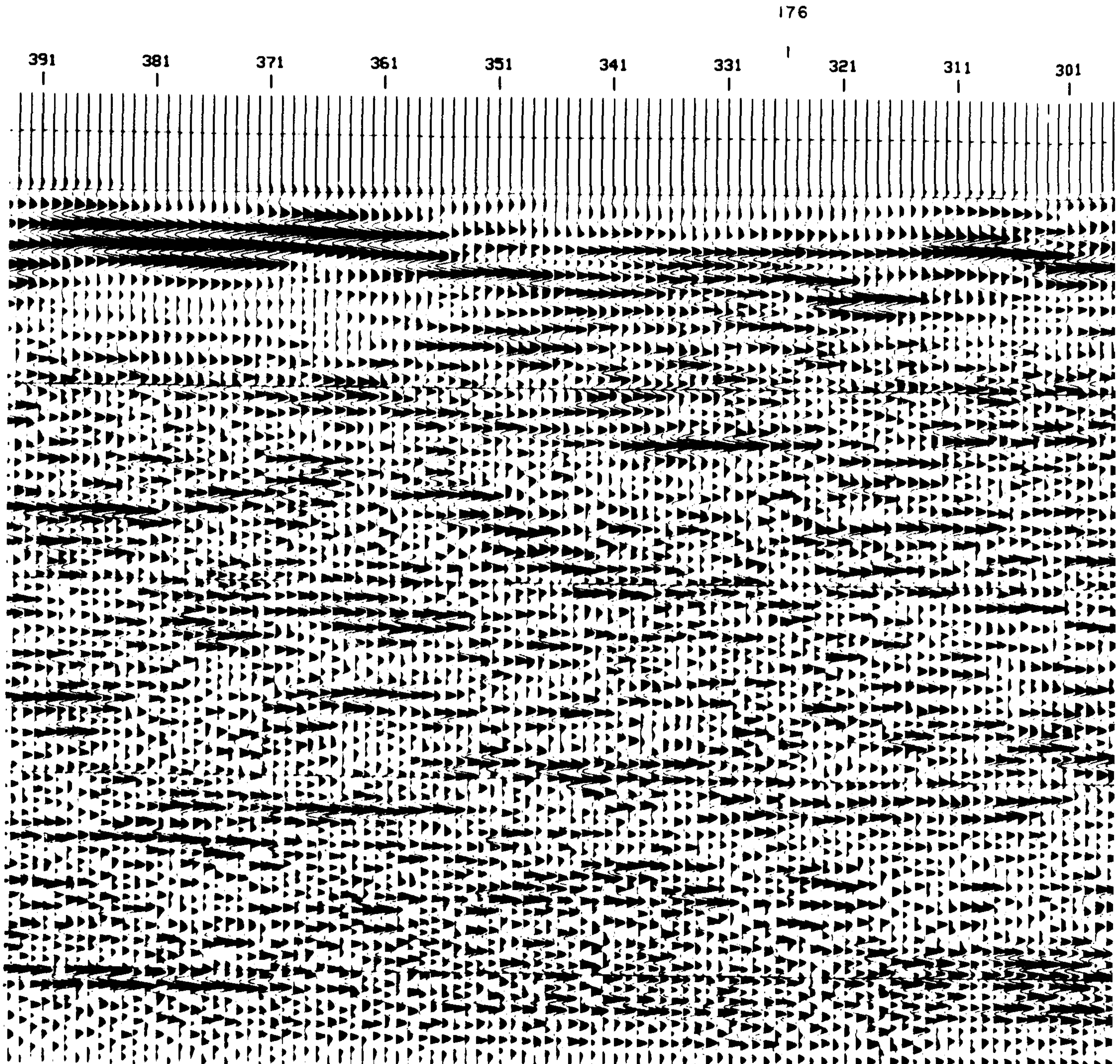
SOUTH NORTH

WAVE EQUATION MIGRATION

FIELD RECORDING

RECORDED BY: CSM CREW	DATE:AUGUST 1986
FIELD SYSTEM: ES-2420	FORMAT:SEGD
ENERGY SOURCE: BUFFALO GUN	SAMPLE INTERVAL: .25 MSEC.
NO. OF SHOTS/HOLE: 3	RECORD LENGTH: .5 SEC.
GROUP INTERVAL: 5 FT.	FOLD: 6
NUMBER OF GROUPS: 24	SHOTPOINT INTERVAL: 10 FT.
GEOPHONE TYPE: GSC-200	GEOPHONE FREQUENCY: 8 HZ.
GEOPHONE ARRAY: 25 FT.	GEOPHONE SPACING: 5 FT.
RECORDING FILTERS: LC: 25 HZ	SLOPE: 18 DB/OCT
HC: 720 HZ	SLOPE: 18 DB/OCT
NOTCH: 60 HZ	

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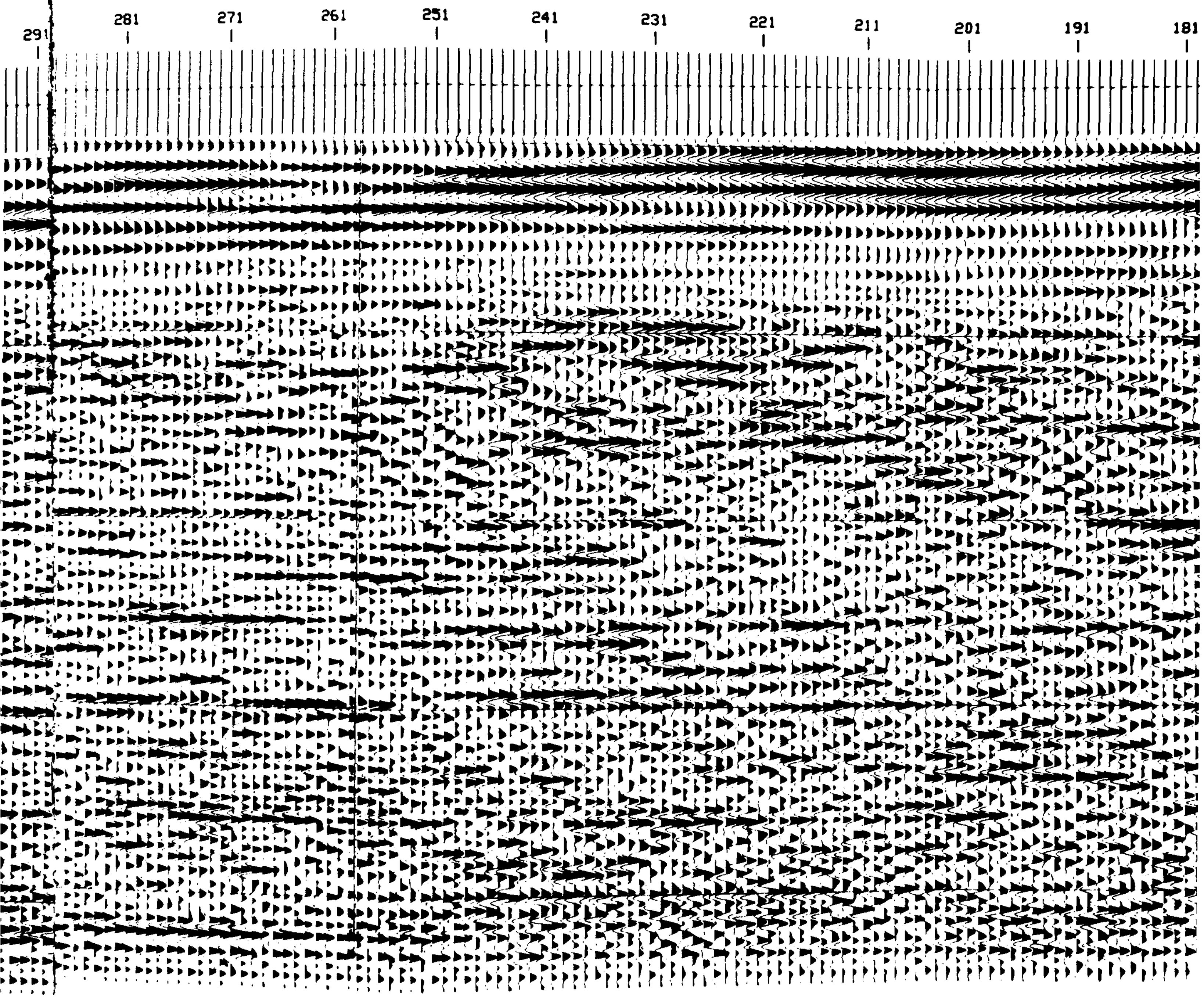
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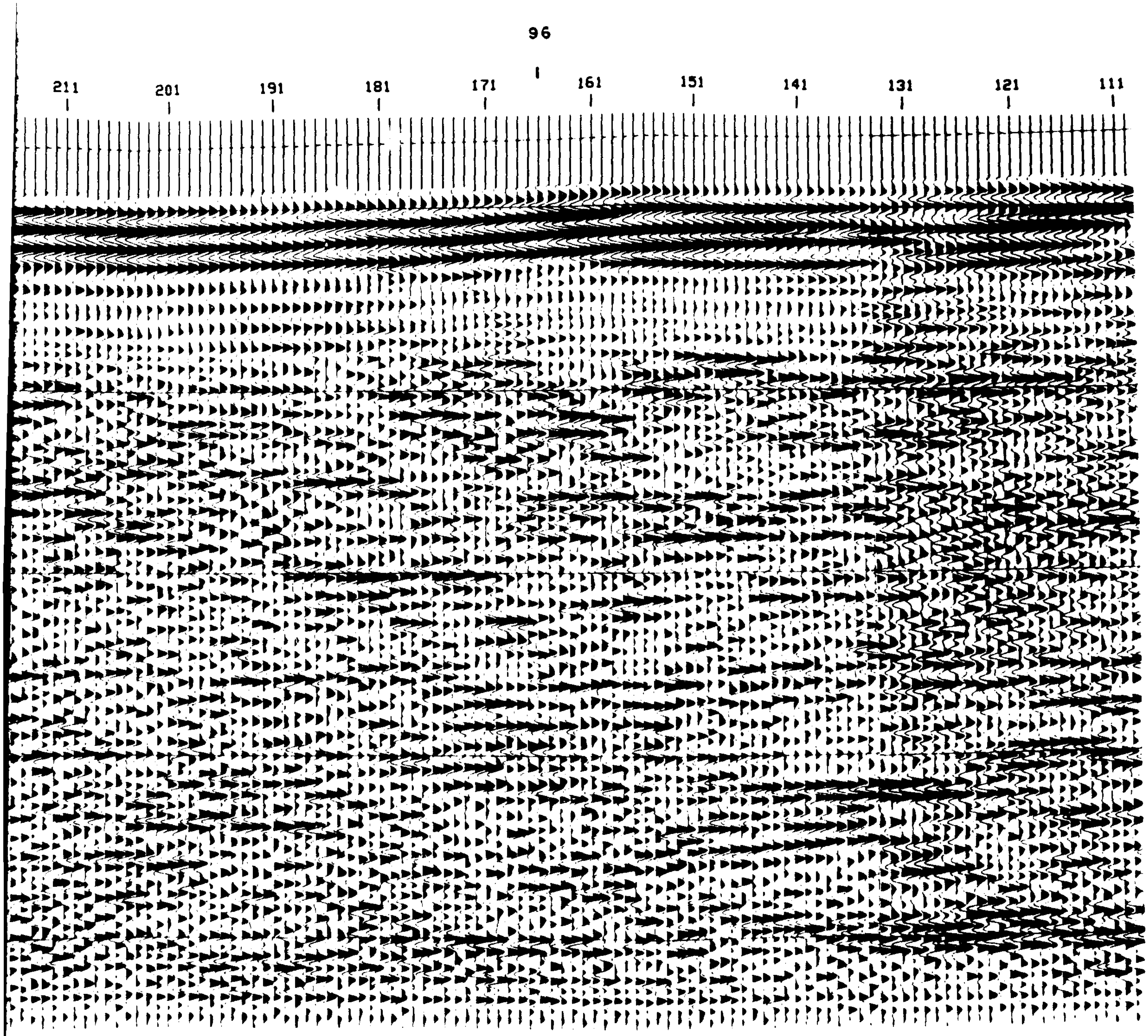

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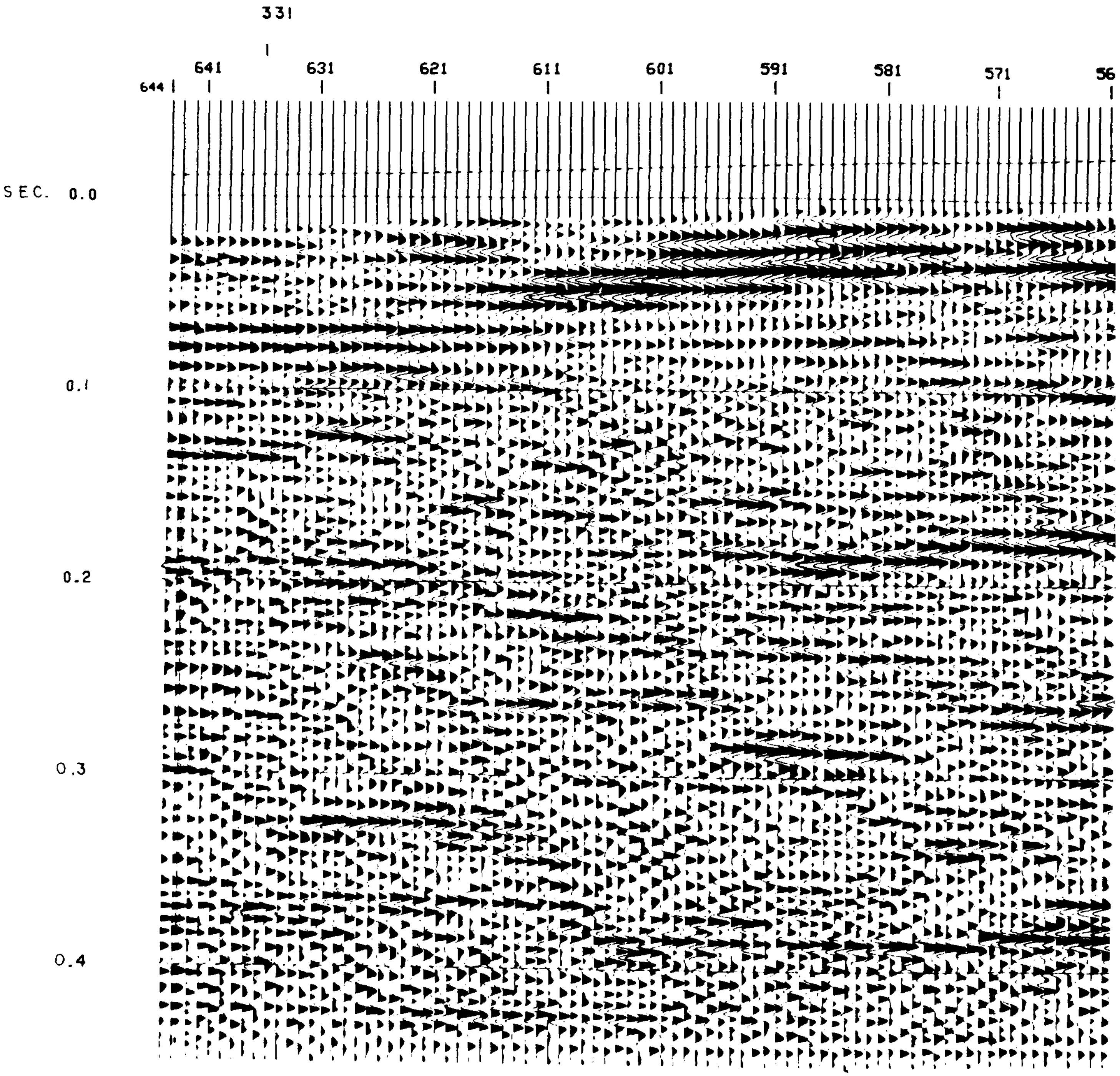
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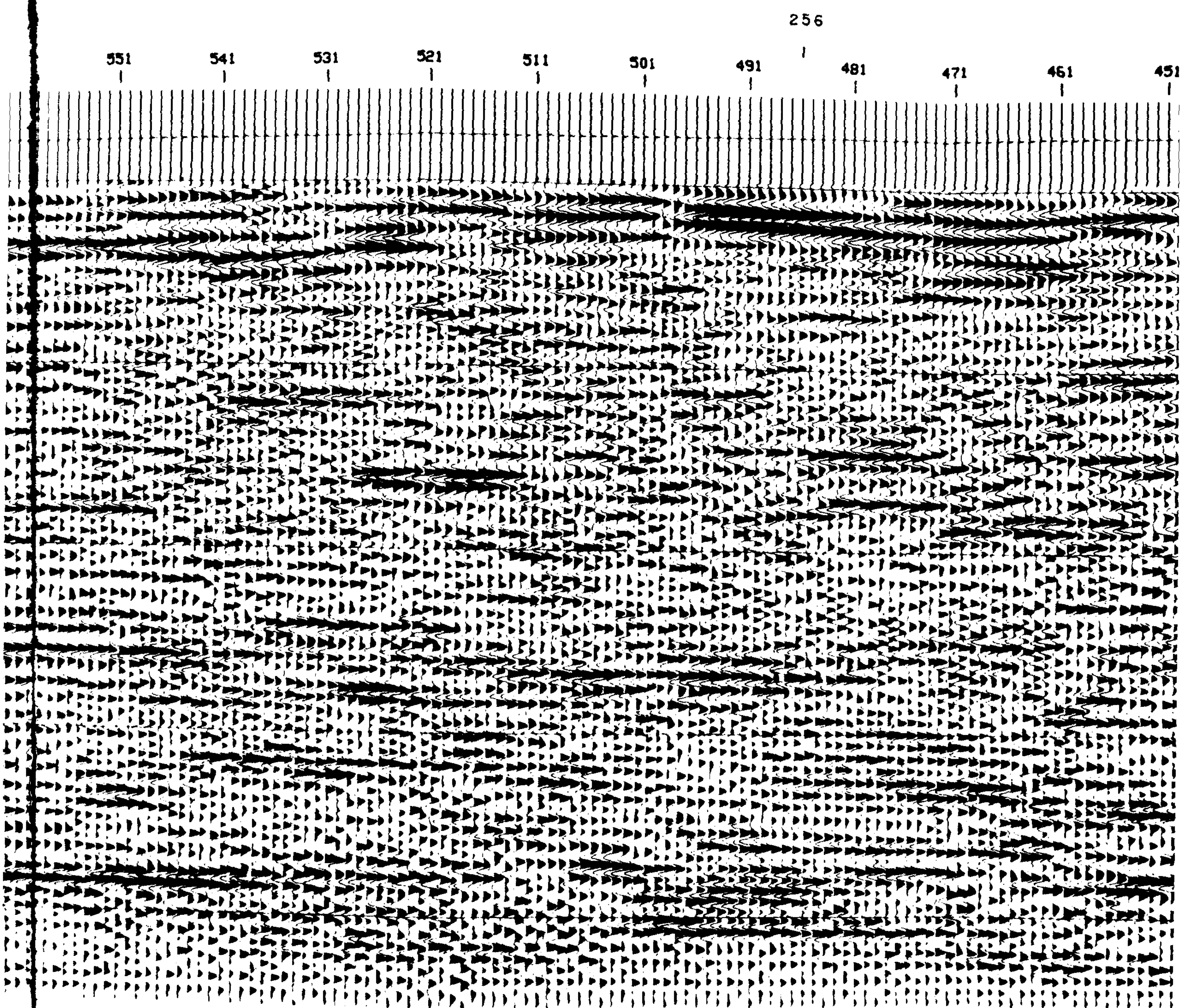

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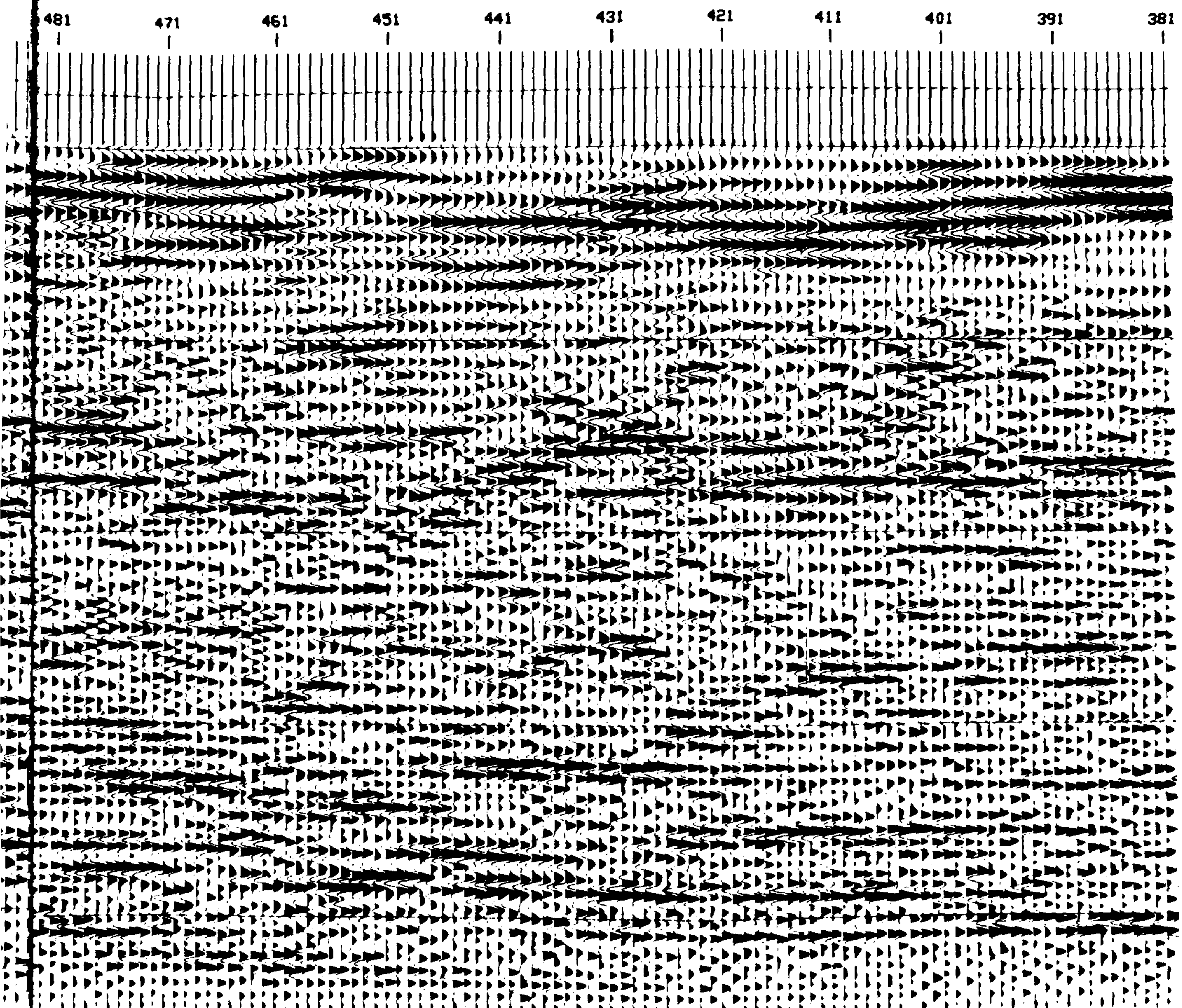

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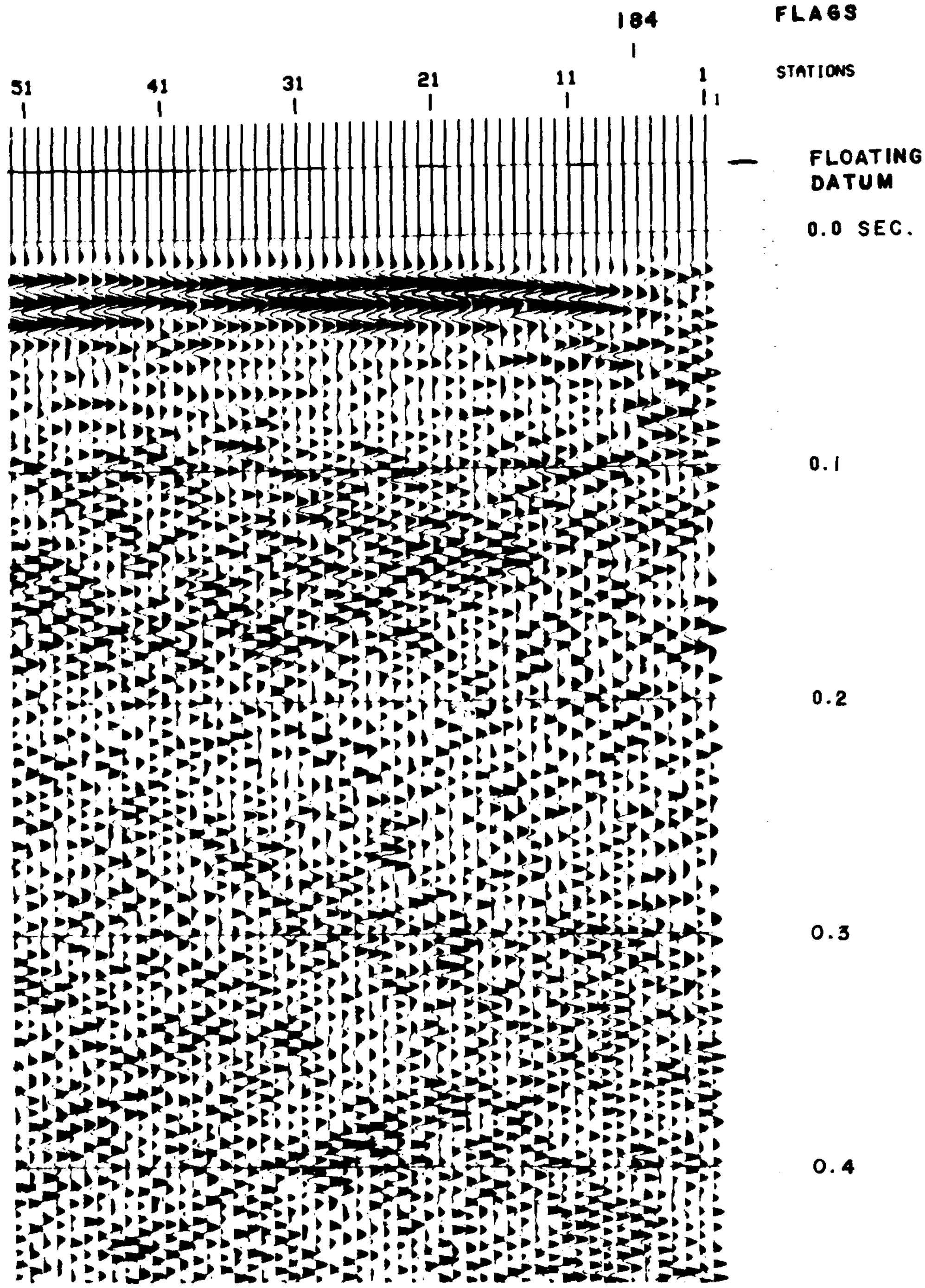

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D AT CGG DATA PROCESSING CENTER
MPA ST., DENVER COLORADO
LANE: 1080 FT. CORRECTIONAL VELOCITY: 2800 FT./SEC.

GEOMASTER
PROCESSING SEQUENCE

01-DEMULTIPLEX
02-GAIN COMPENSATION FOR TRANSMISSION LOSS
AND SPHERICAL DIVERGENCE
03-CDP SORT
04-GEOPHONE EDITS
05-SHOT AND TRACE EDITS
07-STATICS TO FLAT DATUM
08-SPIKING DECONVOLUTION
OPERATOR LENGTH 40 MSEC.
WINDOW FROM 62.5 TO 250 MSEC.
09-AUTOMATIC RESIDUAL STATICS
10-VELOCITY ANALYSIS
11-NMO CORRECTION
12-MUTES
13-AUTOMATIC RESIDUAL STATICS
14-CDP STACK
15-BAND PASS FILTER
72/88-180/220 HZ
16-DYNAMIC TRACE EQUALIZATION
17-STATICS TO FLOATING DATUM
18-FILM DISPLAY

DISPLAY PARAMETERS

HORIZONTAL SCALE: 12 TRACES PER INCH
VERTICAL SCALE: 14 INCHES PER SECOND
POLARITY: FIELD POLARITY

QUALITY CONTROL

BER 1986 CGG ACCT. NO.: 4223101
BY: TANYA MUELLER CHECKED BY: DR. T.L. DOBECKI
MONROE B. SAVAGE

SCALE

33 TR. = 1/64 MILE

F

WATERWAY

288

FINA

RECORDED BY: CS
FIELD SYSTEM: E
ENERGY SOURCE:
NO. OF HITS/HOL
24 SINGLE GEOPH
GEOPHONE TYPE:
GEOPHONE SPACIN
RECORDING FILTE

CH24

240'

PLATE 3

WATERWAYS EXPERIMENT STATION

COMPANY

BEAVER DAM ARKANSAS

AREA

LINE C-3

LINE

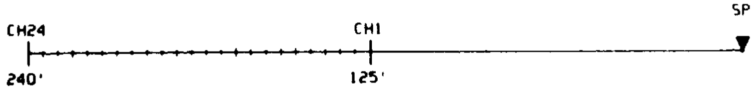
288	STATIONS	1

SOUTH NORTH

FINAL EQUALIZED STACK

FIELD RECORDING

RECORDED BY: CSM CREW	DATE:AUGUST 1986
FIELD SYSTEM: ES-2420	FORMAT:SEGD
ENERGY SOURCE: HAMMER	SAMPLE INTERVAL: .25 MSEC
NO. OF HITS/HOLE: 9	RECORD LENGTH: .5 SEC.
24 SINGLE GEOPHONES	FOLD: 6
GEOPHONE TYPE: CGS	GEOPHONE FREQUENCY: 100 HZ
GEOPHONE SPACING: 5 FT.	SHOTPOINT INTERVAL: 10 FT.
RECORDING FILTERS: LC: 25 HZ	SLOPE: 18 DB/OCT
HC: 720 HZ	SLOPE: 18 DB/OCT
NOTCH: 60 HZ	



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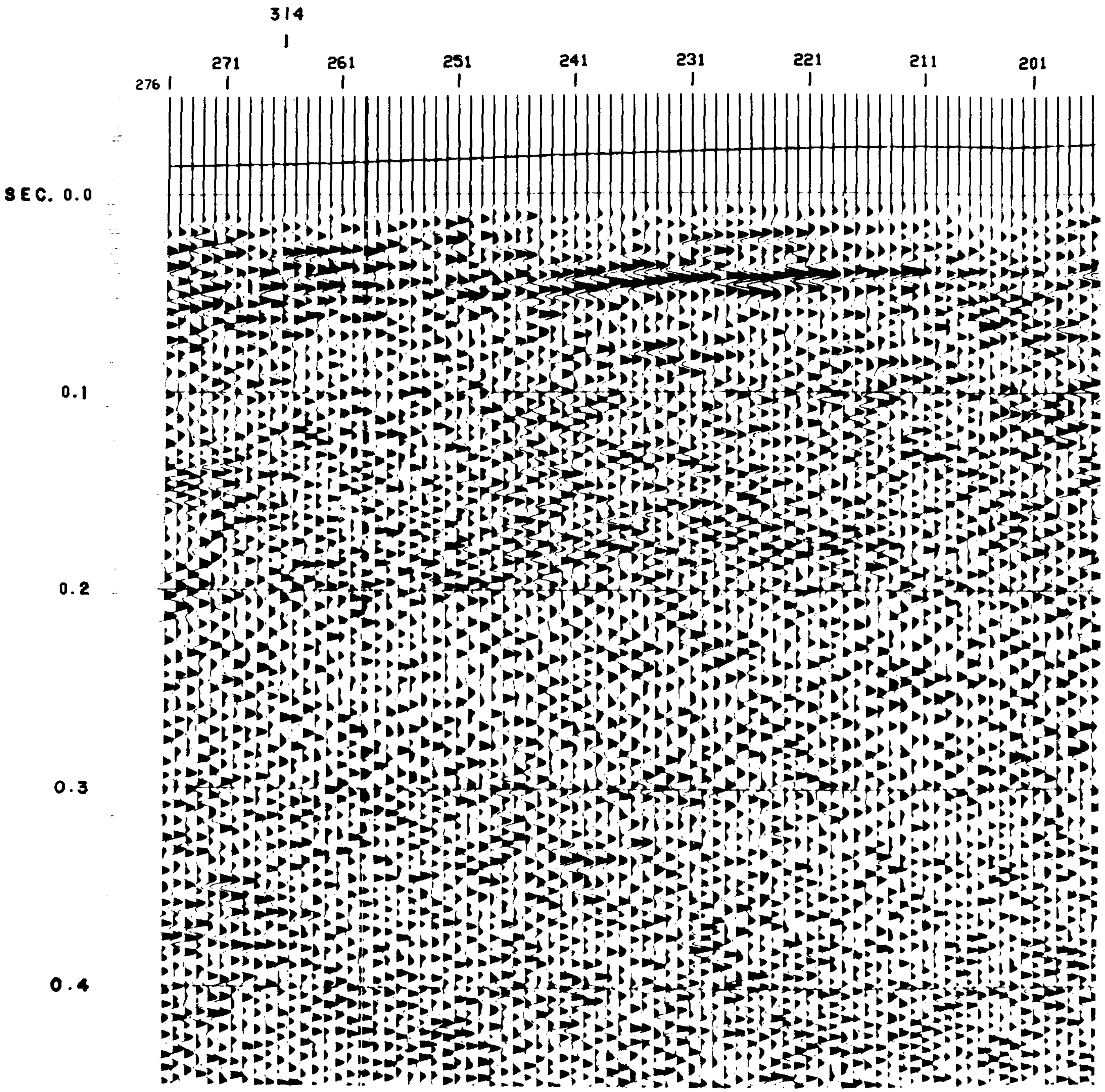
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SEC. 0.0
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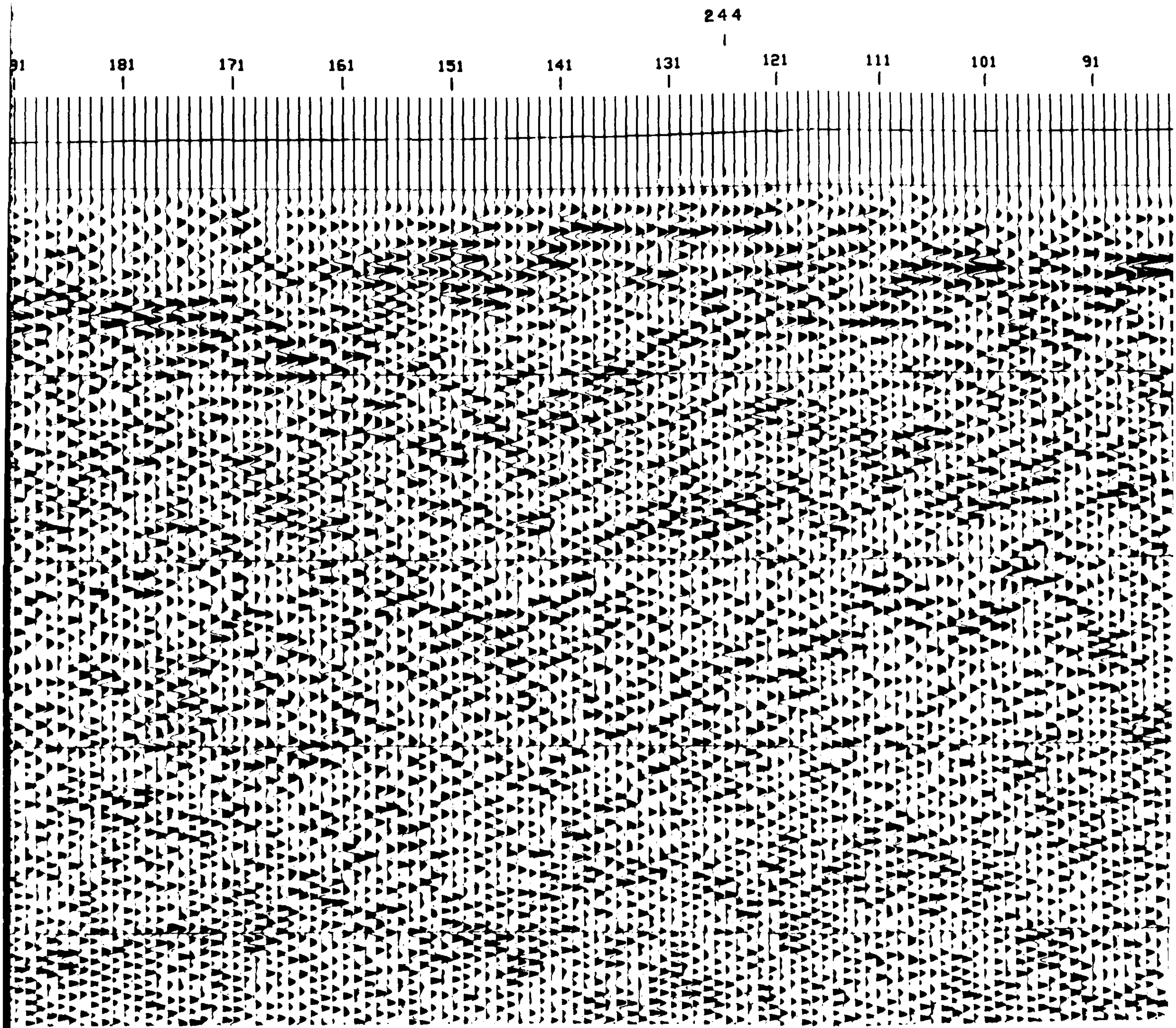

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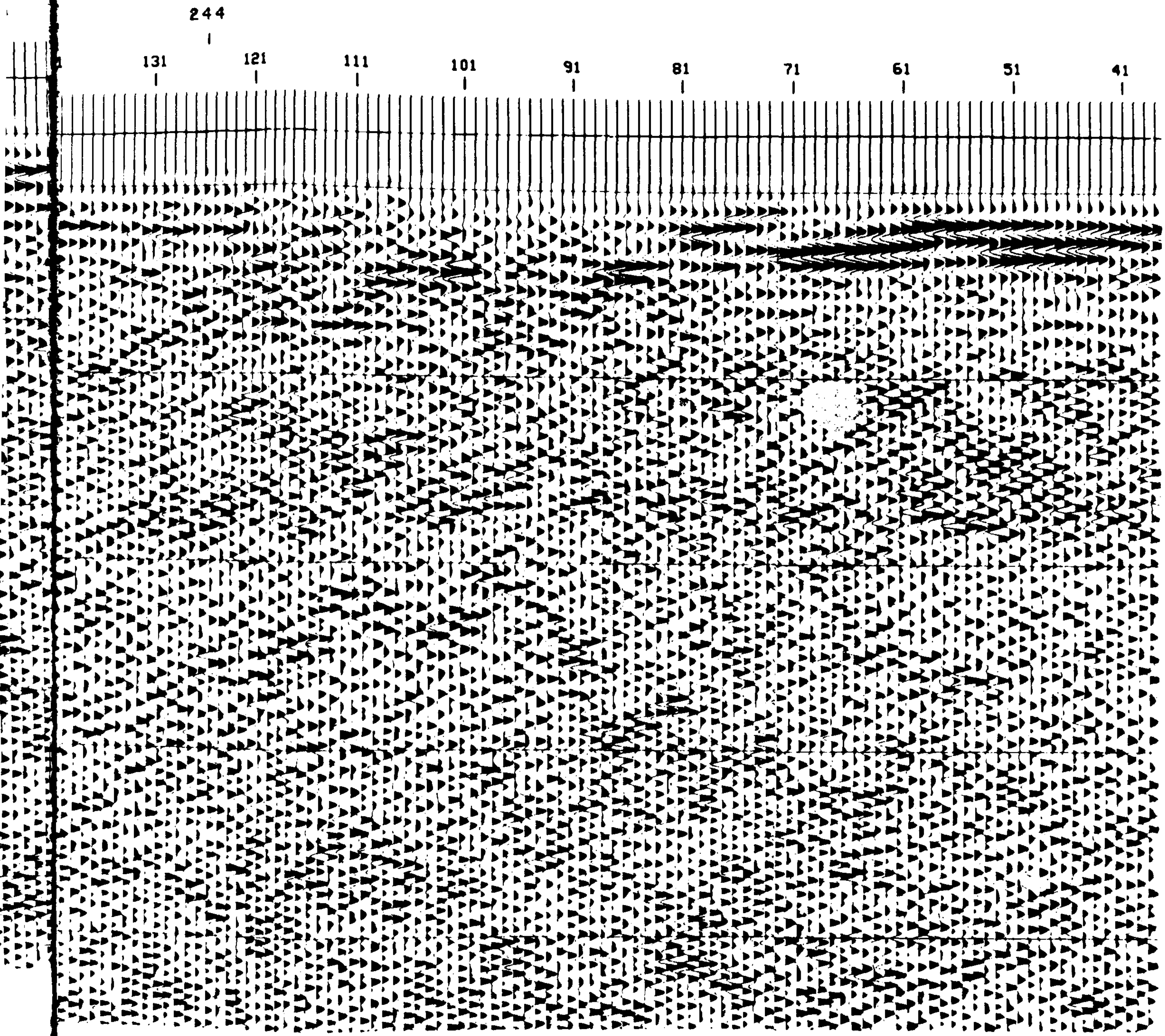
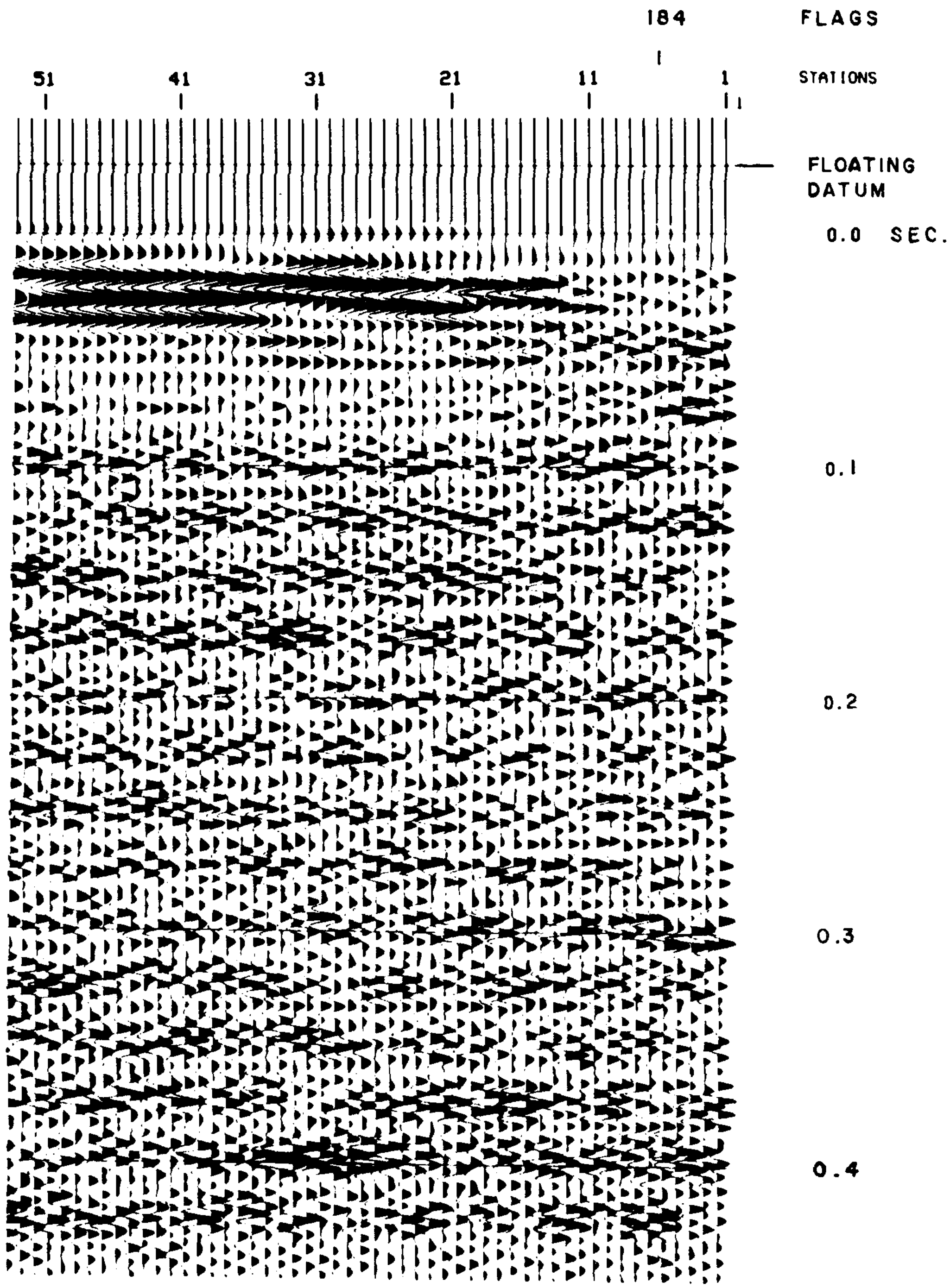


PLATE 3 (Concluded)


184
FLAGS
51
41
31
21
11
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STATIONS
FLOATING DATUM
0.0 SEC.
0.1
0.2
0.3
0.4

COMPUTING

COMPUTED AT CGG DATA PROCESSING CENTER
1616 CHAMPA ST., DENVER COLORADO
DATUM PLANE: 1080 FT. CORRECTIONAL VELOCITY: 2800 FT./SEC.

GEOMASTER PROCESSING SEQUENCE

01-DEMULTIPLEX
02-GAIN COMPENSATION FOR TRANSMISSION LOSS
 AND SPHERICAL DIVERGENCE
03-CDP SORT
04-GEOPHONE EDITS
05-SHOT AND TRACE EDITS
07-STATICS TO FLAT DATUM
08-SPIKING DECONVOLUTION
 OPERATOR LENGTH 40 MSEC.
 WINDOW FROM 62.5 TO 250 MSEC.
09-AUTOMATIC RESIDUAL STATICS
10-VELOCITY ANALYSIS
11-NMO CORRECTION
12-MUTES
13-AUTOMATIC RESIDUAL STATICS
14-CDP STACK
15-BAND PASS FILTER
 72/88-180/220 HZ
16-DYNAMIC TRACE EQUALIZATION
17-STATICS TO FLOATING DATUM
18-WAVE EQUATION MIGRATION
19-BAND PASS FILTER
20-DYNAMIC TRACE EQUALIZATION
21-FILM DISPLAY

DISPLAY PARAMETERS

HORIZONTAL SCALE: 12 TRACES PER INCH
VERTICAL SCALE: 14 INCHES PER SECOND
POLARITY: FIELD POLARITY

QUALITY CONTROL

DATE NOVEMBER 1986 CGG ACCT. NO.: 4223101
PROCESSED BY: TANYA MUELLER CHECKED BY: DR. T.L. DOBECKI
MONROE B. SAVAGE

SCALE

33 TR. = 1/64 MILE

2

PLATE 4

WATERWAYS EXPERIMENT STATION
COMPANY

BEAVER DAM ARKANSAS
AREA

LINE C-3
LINE

288   1
STATIONS

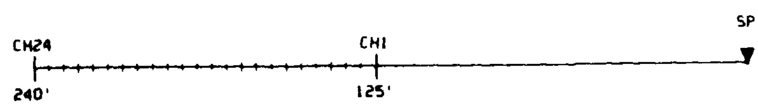
SOUTH   NORTH

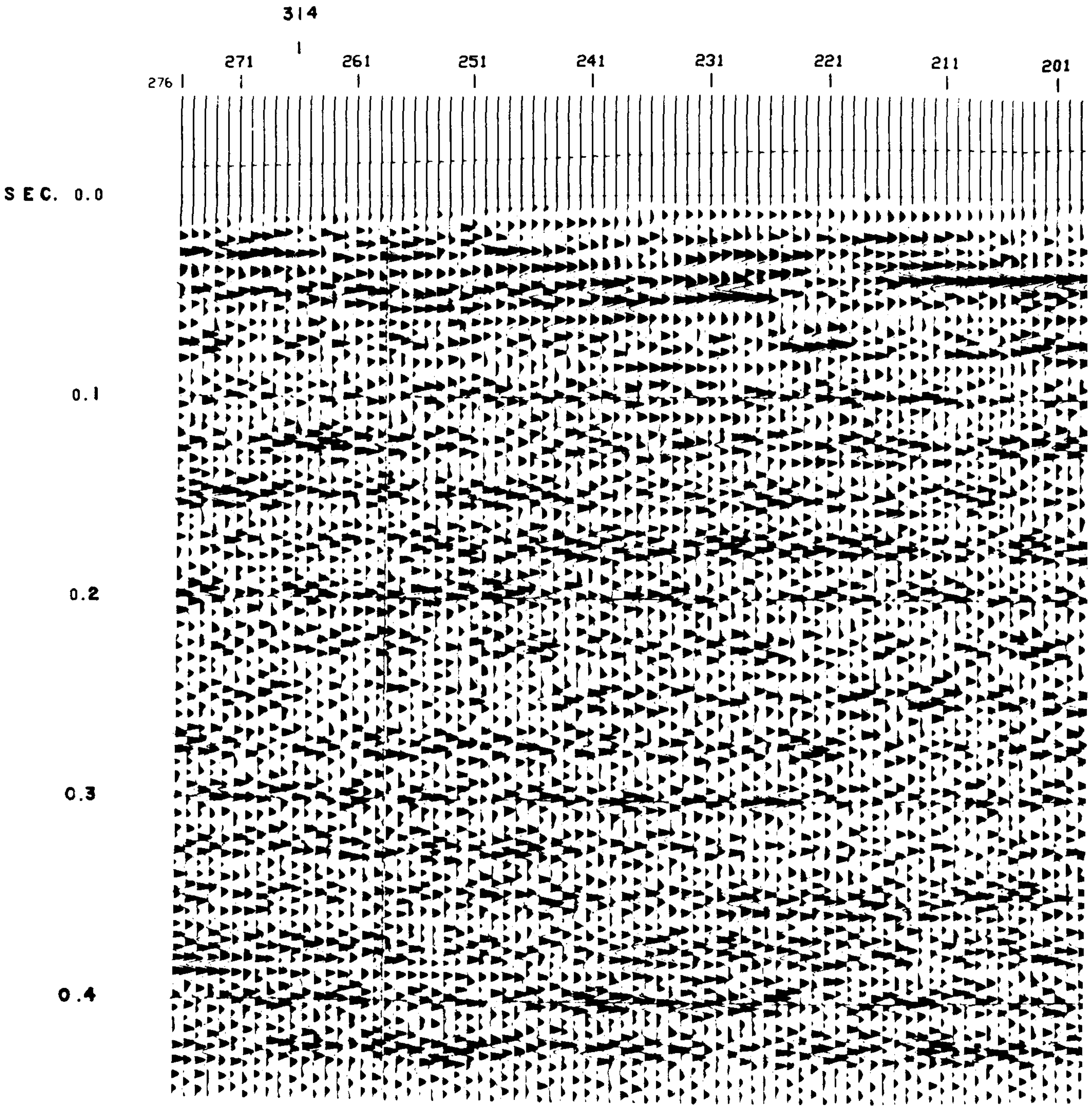
WAVE EQUATION MIGRATION

FIELD RECORDING

RECORDED BY: CSM CREW
FIELD SYSTEM: ES-2420
ENERGY SOURCE: HAMMER
NO. OF HITS/HOLE: 9
24 SINGLE GEOPHONES
GEOPHONE TYPE: CGS
GEOPHONE SPACING: 5 FT.
RECORDING FILTERS: LC: 25 HZ   SLOPE: 18 DB/OCT
HC: 720 HZ   SLOPE: 18 DB/OCT
NOTCH: 60 HZ

DATE: AUGUST 1986
FORMAT: SEGD
SAMPLE INTERVAL: .25 MSEC
RECORD LENGTH: .5 SEC.
FOLD: 6
GEOPHONE FREQUENCY: 100 HZ.
SHOTPOINT INTERVAL: 10 FT.

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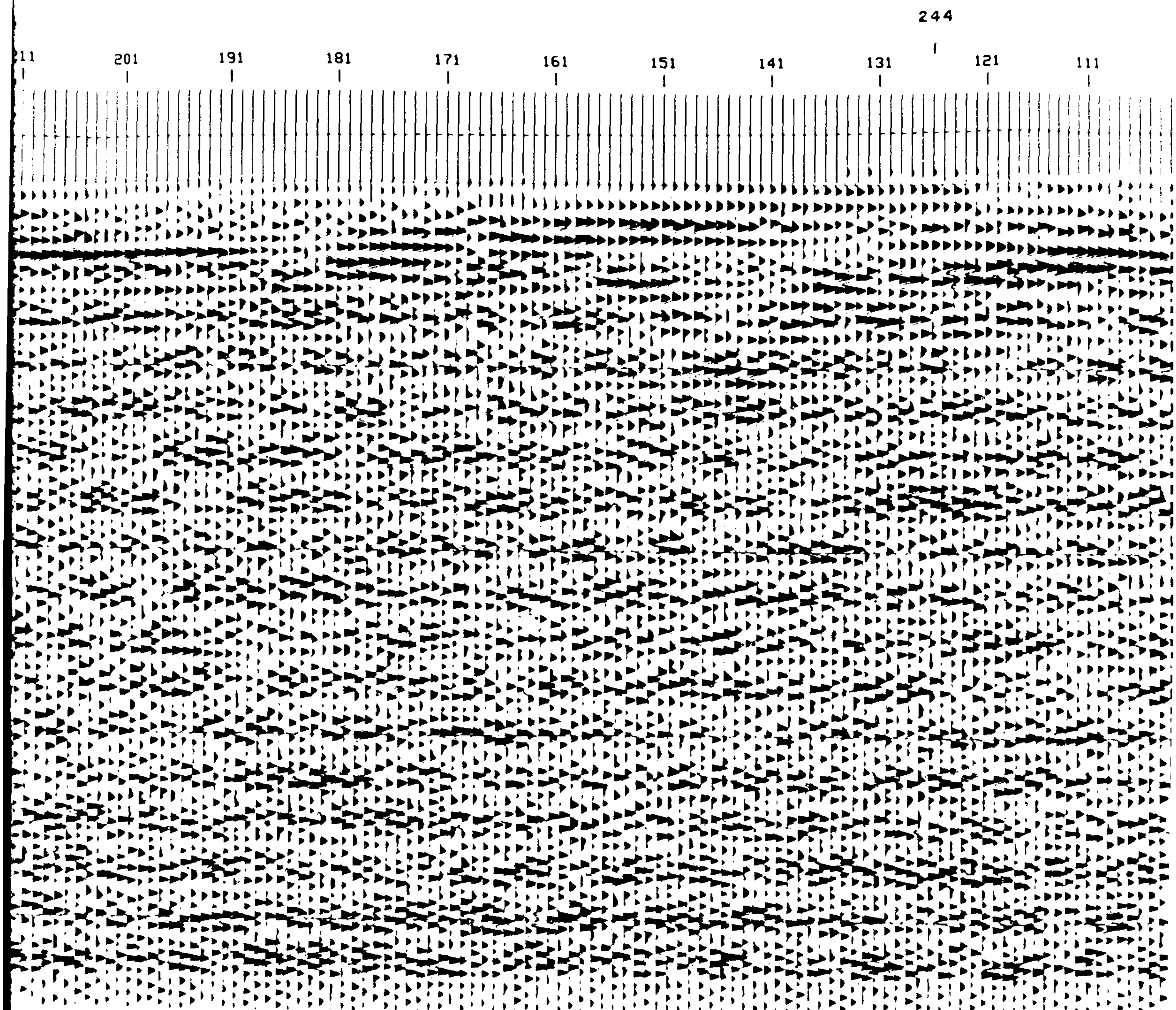
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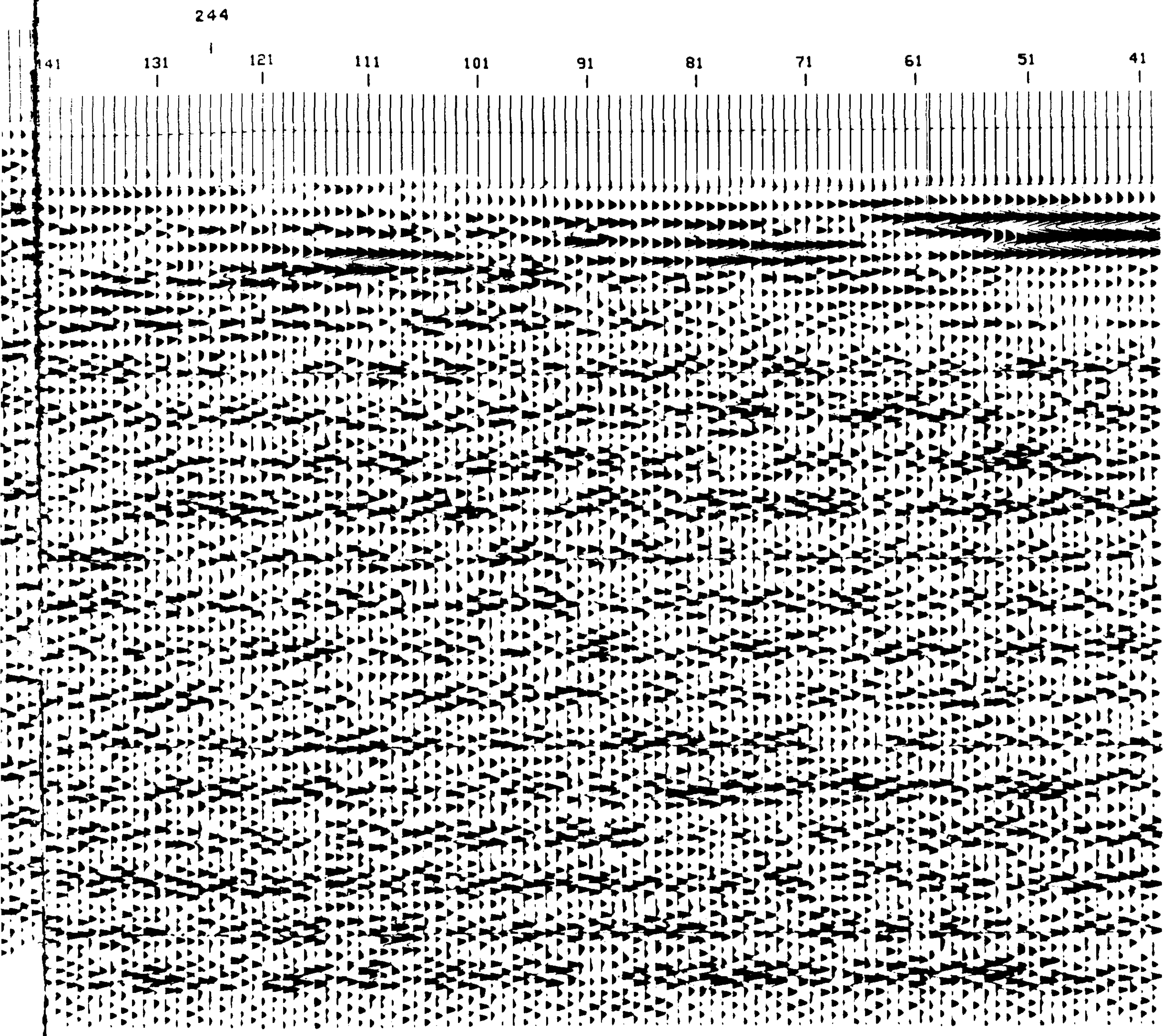

PLATE 4 (Concluded)

APPENDIX A: GLOSSARY*

Amplitude spectrum - amplitude-versus-frequency relationship such as computed in a Fourier analysis.

Autocorrelation - correlation of a waveform with itself...is equivalent to passing a waveform through its matched filter.

Common depth point (CDP) - having the same midpoint between source and detector.

CDP gather - the set of traces which have a common midpoint (see Figure A1).

CDP stack - a sum of the traces corresponding to the same midpoint...corrected for statics and normal moveout (NMO) and then summed (stacked).

CDP method of data acquisition - shooting seismic data in a manner such as to generate CDP gathers (see Figure A2).

Common offset gather - a side-by-side display of traces which have the same shot-to-geophone distance (offset).

Common offset method of data acquisition - see Figure A2.

Deconvolution - a process designed to restore a waveform to the form it had before it underwent a linear filtering action (convolution).

Demultiplex - to separate the individual component channels which have been multiplexed (mixed together).

Elevation statics - see "statics."

F-K velocity filter - discrimination on the basis of apparent velocity.

Floating datum - a variable reference surface used in areas of variable topography.

Fold - the multiplicity of common depth point data.

Gain compensation for transmission loss and spherical divergence - gain applied to a recorded seismic trace to account for decrease in wave strength due to energy absorption by the medium and due to geometric spreading of the wavefront.

Graben - a down-dropped block bounded by normal faults.

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* Taken from Sheriff, R. E., 1984. Encyclopedic Dictionary of Exploration Geophysics: Society Exploration Geophysicists, Tulsa, OK.

Migration - rearrangement of interpreted seismic data so that reflections and diffractions are plotted at the locations of the reflectors and diffracting points rather than with respect to observation points.

Mute - to change the relative contribution of components of a stack with record time.

Normal moveout (NMO) - the variation of reflection arrival time because of shotpoint-to-geophone distance (offset).

Operator length - the time-domain length of the impulse response of a convolution operator.

Optimum offset - the best shotpoint-to-geophone distance for observing a particular reflection in a noise-free window.

Sort - rearrange seismic traces with respect to some attribute shared by each.

Spiking deconvolution - deconvolution in which the desired wavelet is a spike or impulse.

Stack - a composite record made by combining traces from different records.

Statics - corrections applied to seismic data to compensate for the effects of variation in elevation, weathering thickness, weathering velocity, or reference to a datum.

Throw - the vertical component of separation of a rock unit (bed) by a fault.

Time-variant filtering - varying the frequency band-pass with record time.

Vertical seismic profile (VSP) - measurements of the response of a geophone at various depths in a borehole to shots on the surface.

Vugs - large pores in a rock mass from a few millimeters to a few centimeters in size; often caused by dissolution of carbonate minerals.

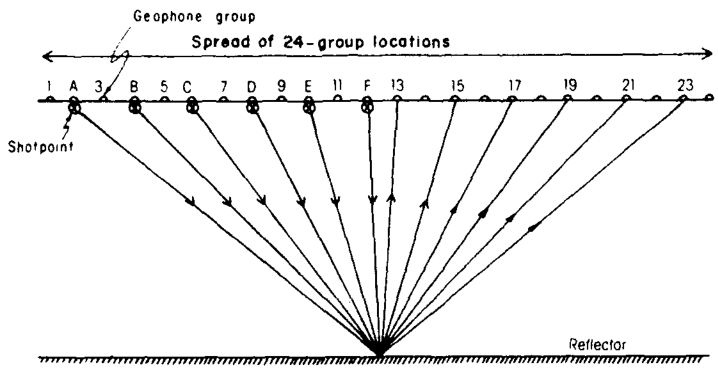

Figure A1. Illustration of a set of seismic raypaths sharing a common midpoint or common depth point

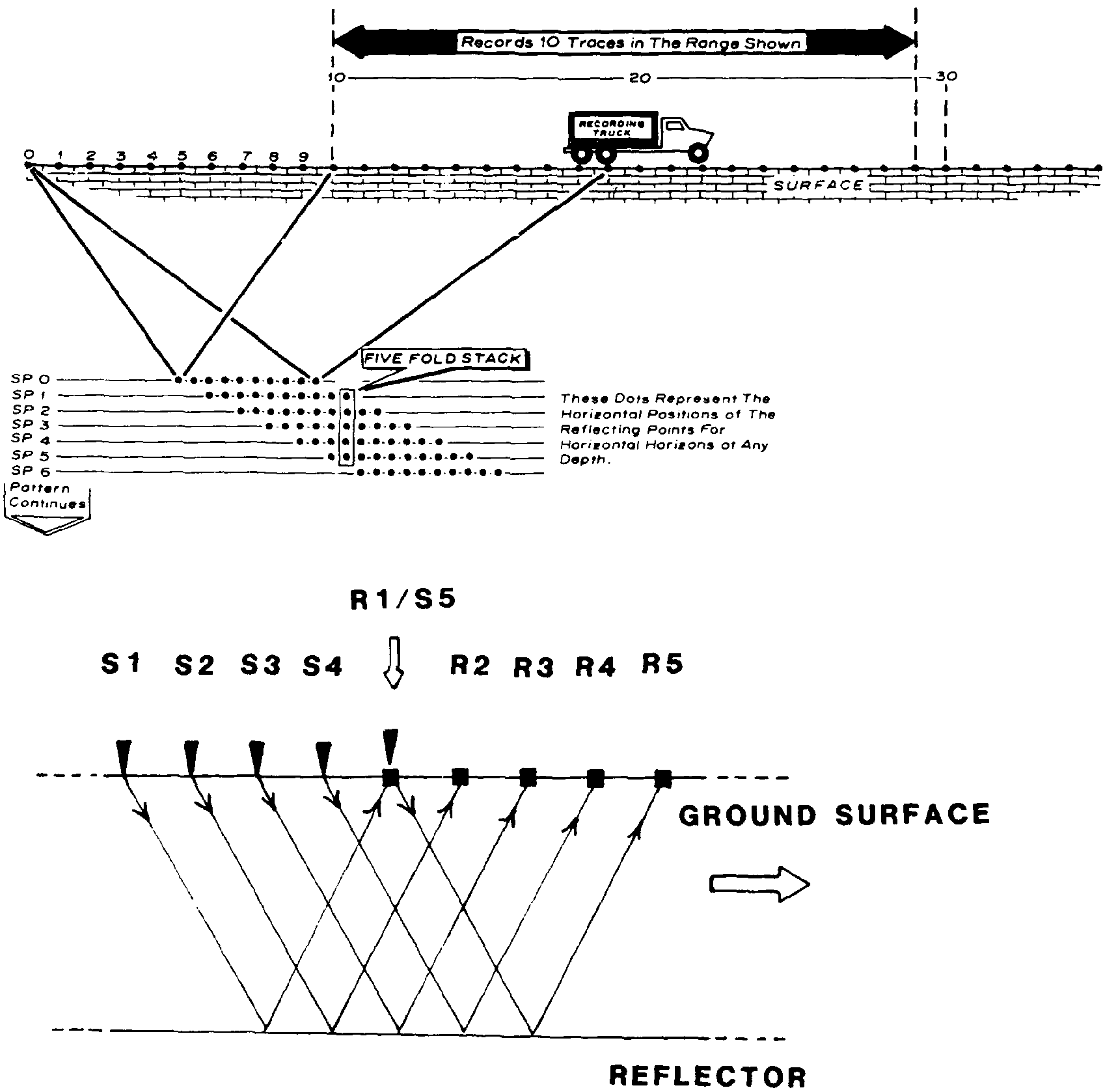

Figure A2. Illustrations of the procedures involved in CDP data acquisition (upper) and common offset data acquisition (lower)